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WITH PLATE V.

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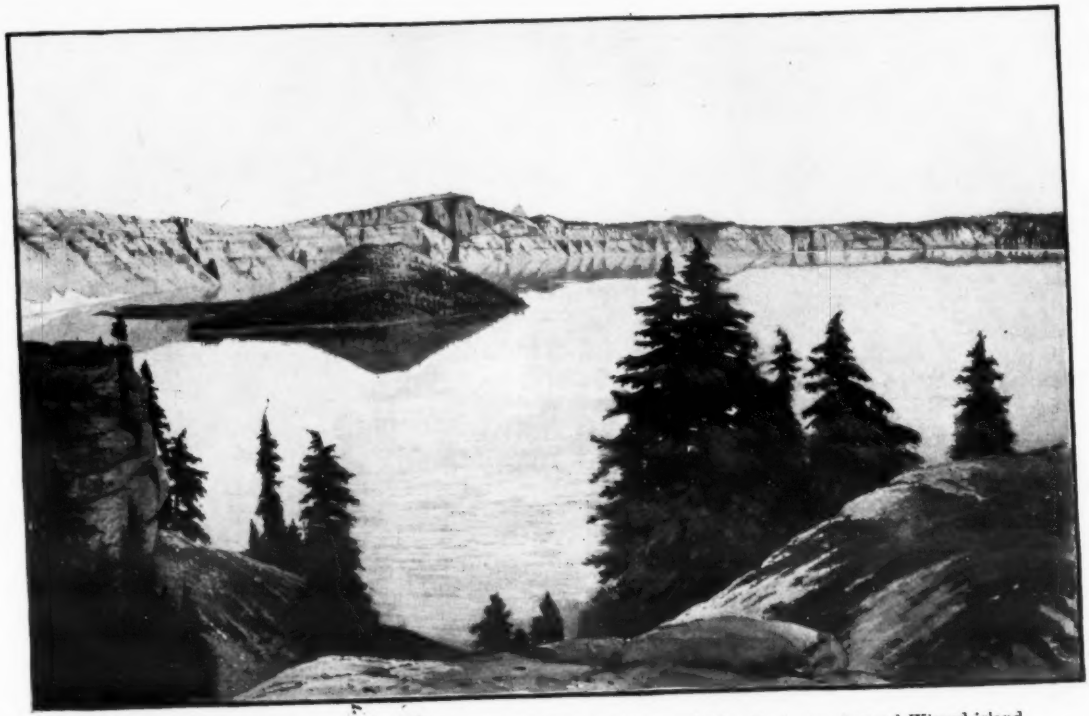

View across the western part of Crater lake. The Devil's Backbone and Llao Rock seen beyond Wizard island.

THE

AMERICAN JOURNAL OF SCIENCE

[FOURTH SERIES.]

ART. XVI.—*Crater Lake, Oregon;* by J. S. DILLER. With Plate V.

THE Crater lakes, Bolsena and Bracciana in Italy, Paven in France and Laach in Germany, besides numerous other examples in various parts of Europe, South and Central America and Asia, have long been known to science, but the one in the United States which, all things considered, is the most imposing of the series, has scarcely been mentioned in scientific publications and its very existence even appears to be generally unknown to persons interested in such features.

The Crater Lake of Southern Oregon is deeply set in the summit of the Cascade Range and is remarkable, not alone for its geological history, of which it contains some especially interesting chapters, but also on account of its geographic position and depth, its beautiful blue transparent waters and the grandeur of its completely encircling cliffs, affording no outlet.

The summit of the range at this point is broad, with gentle, canyoned slopes surmounted by numerous volcanic cones.

The rim of the lake, which is nearly circular, with an average diameter of six miles, rises a thousand feet above the general level of the range. Its outer slope is gentle and rather regular from 10° to 15°, but within, the descent to the lake is precipitous. In general the rim may be described as the hollow base of a very large but deeply truncated cone. Here and there, two to four miles from the crest upon the outer side, are cinder and lava cones, adnate to the great cen-

tral volcano. The crest of the rim varies in height from 6759 to 8228 feet above the sea, i. e. 520 to 1989 above the lake. Its prominences stand at the head of spurs radiating from the lake. Some of these ridges were formed by single streams of lava, but others result from erosion and are separated by deep canyons, such as those of Sand Creek and Sun Creek, which pass directly through the rim.

The rim is composed wholly of lava streams and beds of volcanic conglomerate, dipping away from the lake as shown by the accompanying figure. This is the normal composition and structure of the basal portion of a large volcano.

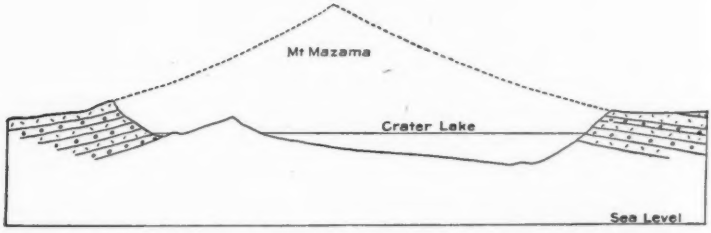

FIG. 1.—Section of Crater Lake and its Rim with the probable outline of Mt. Mazama, structural details generalized—vertical and horizontal scales the same.

The southern and western parts of the rim are made up of many beds; those of lava generally predominate, both in size and number. The northeastern portion of the rim at the Palisades is made up almost wholly of one great flow. The same is true to a less extent at Llao Rock, which is formed of a short but broad stream over 1200 feet in thickness. The exposures upon the inner slope of the rim show sections of the lava streams radiating from the lake, and that of Llao Rock furnishes a good example. Its greatest thickness is in the middle, where it fills an ancient valley, down the northwestern slope of the rim and tapers upon both sides to a thin edge as seen in Plate V. This massive flow rests locally on an irregular layer of pumice and is overlain by the same sort of material.

Andesites predominate, especially among the earlier lava flows so well exposed in section upon the inner slope of the rim; but rhyolites are common among the later ones, and are usually associated with pumice. Basalts were not observed in the rim. However, they occur upon its outer slope several miles away from the crest. They are connected with prominent cinder cones adnate to the once greater central peak and are the newest lavas of the region, excepting that of Wizard Island within the lake. This succession of lavas has been

observed in many large volcanoes and clearly points to Crater Lake as the site of such a mountain.

The rim is intersected by a number of vertical dikes, some of which stand out prominently upon its inner slope. The largest of these, locally known as the Devil's Backbone, varies from five to twenty-feet in thickness, and as seen in the plate, cuts the rim from water to crest one and a half miles southwest of Llao Rock. Nearly a dozen other dikes appear in various parts of the rim, and all radiate more or less directly from the lake. Some of them cut through the older lavas only. Others reach to the top of the rim, but none was seen to penetrate the late flows of rhyolite. The dikes are of andesite, and their radial arrangement, as well as the succession of lavas, point to the middle portion of the lake as the center from which they emanated.

The name Crater Lake suggests that the lake occupies a crater, and it would naturally be supposed that the crater was originally as large as the rim of the lake. That this is not the case, however, is indicated by the following consideration.

No lava came out through the flanks of the rim excepting the basalts which are associated with cinder cones low on its outer slope. The lava streams generally reach up to the crest and radiate from the rim. If the crater were as large as the rim, the lavas must have escaped by overflow from its lowest point, and the inner slope of the rim would bear traces of the rise and fall of the lava within, instead of exposing sections of all the coulees and sheets of conglomerate of which it is made up. The inner slope of the rim is one of fracture and not of flow, and shows that the lava streams once extended farther towards the center of the lake than now and were more elevated in that direction. They issued from the crater or sides of a huge volcanic peak which once stood upon the present site of the lake.

The rim of the lake has been extensively glaciated and affords ample evidence concerning a change in the topography of the region since the glacial period. Moraines are widely spread over a large part of the rim, and extend in some cases far beyond it down the principal lines of drainage upon both sides of the range. The glacial debris is occasionally accumulated in well-defined ridges transverse to the direction of glacial motion, but more commonly is spread over the region in an irregular veneering composed of bowlders, gravel and sand. From the main highway to the lake is a wagon road which ascends over a steep slope littered with many bowlders and irregular piles of glacial debris. On the east of the road is the crest of the range. Against the rim of the lake this crest ends in a prominent moraine ridge marking the line of

separation between the glacial lobes which descended Anna and Castle Creeks on opposite sides of the range.

At many points on the very crest of the rim, glacial debris is well exposed, resting on striated rocks. Occasionally the debris is over 50 feet in thickness, but is rarely composed of large fragments. The largest bowlders, about 10 feet in diameter, were seen some distance from the crest upon the outer side.

Glaciers descended all the valleys upon the outer slope of the rim for from two to five miles. Below, the moraines terminate in plains through which the present streams have cut narrow deep canyons with columned slopes or cliffs, rendering them inaccessible, Their sculptured walls gave name to Castle Creek, but an equally fine display occurs along Anna Creek.

Glacial striæ are well marked at many points, on the very crest of the rim, radiating down the outer slope in some cases for a distance of five miles. The slopes were so generally covered with moving ice that the outlines of the glaciers were not well marked. Probably the largest mass was that of the Divide glacier, which had a width of over four miles upon what is now the rim of the lake. The main portion descended Castle Creek and its branches toward Rogue River, but a large lobe extended down Anna Creek on the eastern slope of the range.

A large mass of ice descended the valley next south of Llao Rock, reaching far down over the broad stream of basalt from Red Cone. The lavas are deeply planed off and striated, but the effect of glacial erosion upon the general topography is not so marked as upon the southern side of the lake, where deep U-shaped canyons have been cut in the older lavas.

That the volcano was active at intervals during the glacial period is well shown by the glaciated flow of Round Top, upon the northeastern edge of the rim. This flow is overlain by two layers of pumice separated by a sheet of rhyolite, all of which were erupted after the glaciation of the surface upon which they rest.

The eruption must have been accompanied by great floods from the snow-capped mountain. Such floods would account for the fact that all the valleys radiating from Crater Lake have been extensively filled with sediments.

Reference has already been made to the occurrence of glacial striæ on the very crest of the rim. They may be seen in many places along the crest northwest of Victor Rock; also a few miles beyond, in the sag of the rim next southwest of Llao Rock, as well as near its summit. They occur also in Round Top, in Kerr Notch and over Eagle Crags, completing

the circuit of the lake from which they radiate. The topmost rocks of the crest are planed off and well striated upon the outer slope, but not upon the steep, broken surfaces which they present to the lake. Glaciation is a feature of the outer slope only, and it is evident that the ice armed with stones to scratch these rocks must have come from above, that is, from a peak which once stood upon the site of the lake.

In the deep, U-shaped canyons of Sun and Sand Creeks there is evidence to the same effect. They extend directly through the rim to the brow of the cliff, over 500 feet above the lake's surface, and belong to a system of drainage which has been completely decapitated. It is impossible to account for the glacial phenomena and drainage features of that region on the supposition that its topography is unchanged.

The succession of lavas and the system of dikes point to a volcanic center within the circle of the rim; but the structure of the rim, the condition of its inner slope and its glacial phenomena go a step further and suggest that during the glacial period the lake did not exist, and that its site was then occupied by a huge volcano which furnished the coulees and sheets of fragmental material in the rim, as well as the masses of ice and snow for its glaciation.

In figure 1, the probable outline of the peak is indicated. Judging from the character of the lava, the slopes of the rim, its size and the extent of its glaciation, it is reasonable to suppose that Mt. Mazama* was once a rival of Shasta and Rainier for the supremacy of the range.

The greatest feature of the region is the enormous pit or caldera containing the lake. It is 4,000 feet deep, extending from the crest of the Cascade Range down half-way to the sea-level. More than a square mile of its bottom is below the level of Klamath Lake, at the eastern base of the range. The pit is half concealed by the lake which so greatly beautifies the scene.

The volume of the pit is nearly a dozen cubic miles, and, if we include the lost peak, it would possibly be half again as large. The problem presented for solution by the removal of such an enormous mass and the development of so great a completely enclosed pit in the process, is one which has not yet been completely solved. There are, however, some phenomena about the lake that throw considerable light upon it, especially when taken in connection with those of similar features in other parts of the globe.

The composition and structure of the mass removed connects its transfer at once with volcanism, and the form of the

* The "Mazamas," a society of mountain-climbers of Portland, Oregon, met at Crater Lake last summer, and christened the mountain, whose remnant still encircles the lake, "Mt. Mazama."

remnants renders it necessary to suppose that it was either blown out by a tremendous volcanic explosion or swallowed up by an equally great engulfment.

The occurrence of a distinct rim at once looks favorable to the explosion method, for rims more or less complete, made up of the ejected materials, are known about many pits formed in that way.* As we have already seen, however, the rim is neither made up wholly or in any part of fragments blown out of the pit, but, on the contrary, is composed throughout of layers of solid lava, alternating with those of volcanic conglomerate and tuff, all of which were erupted from Mt. Mazama before the pit originated. There are, indeed, great quantities of pumice in the region, but that is, at least in part, clearly associated with the last eruptions of Mt. Mazama, for it underlies some of the latest flows, and differs widely from the material (andesite) of which the basal portion of that great volcano was made up. The entire lack, about the pit, of material corresponding in kind, form or quantity to that which would necessarily arise, if the pit were produced by a great explosion, compels us to look in the other direction for the solution of the problem.

While it is true, as shown by Lyell,† Scrope,‡ Judd,§ Geikie‖ and others that the majority of crater lakes occupy basins produced by volcanic explosions alone, there are others, which the same authors recognize as occupying areas a portion of whose depression is attributed to subsidence. Lake Lonar in India has a low rim of fragmental material, but its volume is much less than that of the pit which it surrounds. For this reason the pit is ascribed chiefly to subsidence. Major Dutton¶ has pointed out a number of similar sunken areas or pits, but without lakes, in the Hawaiian Islands, and Dana has described** the sinking of the lava column (molten material), thus deepening the pit, in the yet active volcano of Kilauea. The subsidence of the molten material in the throat of the volcano and

* Volcanoes: The character of their phenomena, etc., by G. Poulett. Scrope, p. 215.

† Elements of Geology, sixth edition, pp. 679–82.

‡ Volcanoes, The character of their phenomena, etc. G. Poulett, Scrope, pp. 222–225.

§ Volcanoes, by J. W. Judd, pp. 170–171.

‖ Text-Book of Geology, third edition, p. 240.

¶ Major Dutton who made a study of Crater Lake, after having visited the great volcanoes of the Hawaiian Islands, came to the conclusion that this depression was "formed in the same manner as the great calderas of the Hawaii Islands" (U. S. Geol. Survey, Eighth Annual Report, p. 158), that is, "by the dropping of a block of the mountain crust which once covered a reservoir of lava, this reservoir being tapped and drained by eruptions at much lower levels." (U. S. Geol. Survey, Fourth Annual Report, p. 105.)

** Characteristics of Volcanoes (1891) p. 127, and Manual of Geology, fourth edition, pp. 284–5.

consequent collapse of the floor of the pit with portions of the surrounding cliffs, are shown to result from the escape of the lava through fissures at much lower levels upon the slope of the mountain. In connection with the subsidence of the lava in Kilauea in 1840 a mass was erupted 27 miles from Kilauea and about 2700 feet below the summit of its cliff. In some cases, however, the sinking of the lava in Kilauea is not known to have been accompanied by an eruption of lava upon the surface.

The view that the caldera of Crater Lake originated by subsidence appears especially applicable for the reason that it occurs in the summit of a prominent range. The western slope of the range, although not steep, is considerably more inclined than that of Kilauea; and within 15 miles of the lake, the level of its deepest bed appears upon the surface. The engulfment of Mt. Mazama and the production of such an enormous pit in the process may well be expected to have given rise to eruptions upon the lower slopes of the range at no very great distance from the lake.

That Mt. Mazama actually disappeared by subsidence is plainly suggested by the behavior of the last erupted lava. It is a rhyolite which escaped from the north slope of Mt. Mazama. Its broad stream follows a shallow valley that now appears in the rim at the head of Cleetwood Cove. Upon the outer slope of the rim, opposite the cove, there is a long depression down the surface of the flow where cliffs, columns and angular blocks occur in great confusion. They have resulted from the caving in of the crust of the lava tunnel in the valley filled by the thickest portion of the flow. But on both sides the lava surface is smooth and easily traversed.

Upon the inner slope of the rim is an equally remarkable and exceptional feature. Descending from the Rugged Crest, at the upper end of the broken tunnel, to the lake is a flow several hundred yards in width. It is part of the large stream of rhyolite which spread upon the outer slope of the rim, and has flowed inwards towards the lake over the broken ends of the older coulees of andesite. The fluidal structure, as well as the parting planes produced by it, are well marked approximately parallel to the inner slope of the rim. It is the only inward-flowing lava found anywhere on the rim, and appears to indicate that before the thickest portion of the final flow of rhyolite had completely solidified, Mt. Mazama was engulfed, and the yet viscous lava followed it towards the abyss.

It might be supposed that a study of the features upon the bottom of the great pit would disclose the character of the change by which it was produced; but this is not the case. Its original surface is in large part, if not wholly, covered by

the products of later volcanic eruptions. We have an excellent opportunity to study this portion of the pit on Wizard Island, where the bottom rises above the surface of the water. The island, near the center of the view in plate V, is formed of a cinder cone and lava field, which are practically unchanged since their recent eruption.

The steep-sloped cinder cone, 845 feet in height, is surmounted by a perfect crater 80 feet in depth. The encircling lava field, made up of angular blocks of dark lava broken up at the time of the eruption, is rough in the extreme.

Judging from Wizard Island, one might expect that there were other piles of recent cinders and lava upon the bottom of the pit, and so it seems; for according to the soundings of the lake made by Captain, now Major, Dutton in 1886,* there are two such prominences rising from great depths, but failing by over four hundred feet to reach the surface of the water. The eruptions of lava and fragmental material upon the bottom of the pit have partially filled it up, but how much has been lost in depth by these final outbursts cannot be estimated.

To epitomise: The history of Crater Lake and its rim began in the upbuilding, by normal volcanic processes, of a large volcano, Mt. Mazama, comparable in the nature of its lavas, structure and size with the greater peaks of the Cascade Range.

Crater Lake did not then exist. Its site was occupied by Mt. Mazama, which was an active volcano in the glacial period. Glaciers descended from its higher slopes, scratching the rocks and depositing moraines about its base.

The later eruptions of Mt. Mazama occurred in the glacial period and doubtless produced extensive floods which filled with debris the valleys of all the streams radiating from the mountain.

In approximate connection with its final eruption, the molten material of the interior withdrawing, the summit of Mt. Mazama caved in and sank away, giving rise to a caldera nearly six miles in diameter and 4,000 feet deep. Thus originated the great pit in which Crater Lake is contained, encircled by a glaciated rim, the hollow base of the engulfed Mt. Mazama.

Upon the bottom of the caldera, volcanic activity continued. There were new eruptions building up cinder cones and lava fields and partially refilling the great pit.

Precipitation is greater than evaporation in that region. Volcanic activity ceasing, the conditions were favorable for water accumulation, and Crater Lake was formed in the pit.

Washington, D. C.

*Eighth Annual Report, Part I, pp. 157–8.

ART. XVII.—*On the Origin and Relations of the Grenville and Hastings Series in the Canadian Laurentian;* by FRANK D. ADAMS and ALFRED E. BARLOW, with remarks by R. W. ELLS.*

As the exploration of the more remote portions of the great Canadian protaxis of the North American continent progresses, accompanied by the detailed mapping of its more accessible parts, the true character, structure and origin of the Laurentian System is being gradually unfolded. The work of Logan during the early years of the Canadian Geological Survey, though excellent in the main, is being supplemented and, in certain directions, corrected; and as the work is now being pushed rapidly forward, it is believed that the time is not far distant when, difficult as the study is, we shall possess as complete a knowledge of these ancient rocks as we now do of many more recent formations. In a paper which appeared in 1893,† it was demonstrated that Logan's "Upper Laurentian" does not exist as an independent geological series, the anorthosites, which were considered as constituting its main feature, being in reality great intrusive or batholitic masses; while in a subsequent paper,‡ it was shown that in the remaining portion of the Laurentian, two distinct classes of rocks could be distinguished, the first being beyond all doubt igneous rocks, and the second consisting of highly altered rocks of aqueous origin. In addition to these two classes of rocks of which the origin could be recognized, there was yet a third class, concerning the genesis of which there remained some doubt.

Since the appearance of these papers, the present writers have been working together in mapping a large area (about 4800 square miles) of the Laurentian in central Ontario, comprising map-sheet No. 118, and a portion of 119, of the Ontario series of geological maps, the district lying to the north of Lake Ontario, along the margin of the Protaxis, and being especially well suited for purposes of study. Portions of three summers have already been spent in the district, and as two years more must probably elapse before the work can be completed, it is desired here to present a general outline of the results so far obtained, indicating certain conclusions which seem likely to be reached concerning the origin of the rocks in question.

The Fundamental Gneiss, as shown by the work of the Canadian Geological Survey, occupies by far the larger portion of the protaxis as a whole; while the Grenville Series has prob-

* Published by permission of the Director of the Geological Survey of Canada.

† Adams F. D.—Ueber das Norian oder Ober-Laurentian von Canada, Neues Jahrbuch für Mineralogie. Beilage Band viii, 1893.

‡ Adams, F. D.—A Further Contribution to our Knowledge of the Laurentian, this Journal, July, 1895.

ably its principal development along the southeastern margin, although as the exploration of this vast area is continued, new and possibly more extensive areas of these rocks may yet be found. Strata belonging to this series are already known to occur on the upper Manicuagan River, the lower Hamilton River, on the Manouan Branch of the Peribonka and on the lower part of the Ungava River, in the Labrador peninsula; while similar rocks, which would seem to belong to this series, but which have not as yet been thoroughly examined, have been met with about southern Baffin's Land, and possibly about Baker Lake near the head of Chesterfield Inlet, as well as on the west coast of Hudson Bay and also at Cross Lake on the Nelson River.

The Fundamental Gneiss consists of various igneous rocks closely allied in petrographical character to granites, diorites and gabbros, and which almost invariably have a more or less distinct foliation. Where this foliation is scarcely perceptible it becomes very difficult to decide whether the rock is an intrusive granite or diorite, or a very massive form of the gneiss in question. The different varieties of gneissic rock alternate with or succeed one another across the strike, or sometimes cut one another off, suggesting a complicated intrusion of one mass through the other, but there is usually a general direction of strike to which, in any particular district, the foliation of all the varieties conform. The associated basic rocks are very dark or black in color and are usually foliated, but sometimes this foliation is absent and the rock occurs in masses of all sizes and shapes scattered through the acid gneisses, and in the great majority of cases so intimately associated with the latter that it is impossible to separate the two in mapping. The smaller of these masses can be distinctly seen to have been torn from the larger, which latter are often of enormous size. This process can be observed in all its stages. The granitic gneiss invades the great basic masses, sending off wedge-like arms into them, which tear them apart and anastomose through them in the most complicated manner. These smaller masses can then be observed to be separated into still smaller fragments, which either from the fact that they split most readily in the direction of their foliation or owing to subsequent movements, when the rock was in a more or less plastic condition, often assume long ribbon-like forms. That great movements have taken place in the whole series during or after this invasion is shown by the complicated twisting of these darker bands and masses into all manner of curious and intricate forms, as well as in the frequent rolling out of great blocks of the amphibolite, after having been penetrated in all directions by small pegmatite veins, resulting in masses of a dark basic gneissoid rock, filled with strings, bunches, separated fragments or grains of quartz or feldspar, giving to the mass a pseudo-conglomeratic appearance.

There can be but little doubt that the various gneissic rocks, constituting the more acid part of the series, are of truly igneous origin; and there is no evidence whatever of their having ever formed part of a sedimentary series.

The true character of the more basic members is more uncertain, but they are probably closely related to the pyroxene granulites of Saxony, and doubtless represent either differentiation-products of the original magma, or basic intrusions whose structural relations and characters have been largely masked by the great movements which have taken place in the whole series at a later date.

The Grenville Series differs from the Fundamental Gneiss in that it contains certain rocks whose composition marks them as highly altered sediments. These rocks are chiefly limestones, with which are associated certain peculiar gneisses, rich in sillimanite and garnet, having a composition approaching ordinary shale or slate, or else very rich in quartz and passing into quartzite, having thus the composition of sandstone. These rocks, as has been shown in one of the papers before referred to, usually occur in close association with one another, and are quite different in composition from any igneous rocks hitherto described. They are considered as constituting the essential part of the Grenville series. They usually, however, form but a very small proportion of the rocky complex in the areas in which they occur, and which, owing to their presence, is referred to the Grenville series. They are associated with and often enclosed by much greater volumes of gneissic rocks, identical in character with the Fundamental gneiss. The limestones are also almost invariably penetrated by masses of coarse pegmatite, and occasionally large masses of the limestone are found embedded in what would otherwise be supposed to be the Fundamental gneiss. The whole thus presents a series of sedimentary rocks, chiefly limestones, invaded by great masses of the so-called Fundamental Gneiss, and in which, possibly, some varieties of the gneissic rocks present may owe their origin to the partial commingling of the sedimentary material with the igneous rocks by actual fusion. There is, however, no reason to believe, from the evidence at present available, that any considerable proportion of the series has originated in the last mentioned manner.

It will be readily seen that an exact delimitation of areas of the Grenville series is thus sometimes a matter of great difficulty, as they often appear to shade away into the Fundamental gneiss, and it has hitherto been difficult in the case of the Grenville series to account for the existence of such a comparatively small proportion of sedimentary strata, intimately associated with such great volumes of igneous gneisses.

The relations of the two series, as determined by the investigations of the last two seasons, throws new light upon the subject, and indicates the probable explanation of the difficulty.

The northwestern half of the more restricted area at present under consideration is underlain by Fundamental Gneiss, presenting the characters described above. A smaller area of the same gneiss occurs at the southwestern corner of the area, in the townships of Lutterworth, Snowdon and Glamorgan, while in the southern and southeastern portions of the area there are other occurrences, which, however, present a more normally granitic character.

The southeastern portion of the area is underlain by rocks of the so-called Hastings Series, consisting chiefly of thinly-bedded limestones, dolomites, etc., cut through by great intrusions of gabbro-diorite and granite. These limestones and dolomites are usually fine-grained and bluish or greyish in color, with thin interstratified layers, holding sheaf-like bundles of hornblende crystals. As compared with the limestones of the Grenville series they are comparatively unaltered. They form beyond all doubt a true sedimentary series, and in the southeastern corner of the area are associated with conglomerates or breccias of undoubtedly clastic origin. Between the great area of Fundamental Gneiss in the northwest, and the Hastings series in the southeast of the sheet, there lies an irregular-shaped belt of rocks, presenting the characters of the typical Grenville series as above described, the limestones having in all cases the form of coarsely crystalline, white or pinkish marbles, although more or less impure. The strike of the foliation of the Grenville series follows in a general way the boundaries of the Fundamental Gneiss, and is seen in an especially distinct manner to wrap itself around the long and narrow development of the gneiss exposed in the southwest corner of the area. Isolated masses of the limestone and gneiss characteristic of the Grenville series are also found in the form of outlying patches about its margin, as for instance in the townships of Lutterworth and Stanhope. The relations of the Grenville series to the Fundamental gneiss are such as to suggest that in the former we have a sedimentary series later in date than the Fundamental Gneiss, which has sunk down into and been invaded by intrusions of the latter series when this was in a semi-molten or plastic condition. The limestones, while themselves rendered more or less plastic by the same heat which softened the lower gneisses, do not show any distinct evidence of absorption or solution by the invading rocks, unless some of the highly garnetiferous gneisses usually associated with the limestones are formed by a commingling of the two rocks. Masses of the highly crystalline limestone or marble in some cases lie quite isolated in what are, to all appearances, the lower gneisses, as if they had been separated from the parent mass, and had passed outward or downward into the gneissic magma.

The contact of the Fundamental Gneiss and the Grenville series would appear therefore to be a contact of intrusion, in very many cases at least.

The question of the relations of the Grenville series to the Hastings series then presents itself. Although repeated traverses have been made from one series into the other, no sharp line of division has been found. Towards the southeast the limestones of the Grenville series in many places, though still highly crystalline, seem to be less highly altered, and finally, as the Hastings series is approached, present in places the bluish color of the limestones of the latter series; so that it is often impossible to determine to which series they should be referred. The limestones of both series also have the numerous small interstratified gneissic inclusions or bands so frequently referred to in the descriptions of the limestones of the Grenville series, making the resemblance still more complete. In fact, although the true relations of the two series are obscured by the presence of numerous great intrusions of granitic and basic pyroxenic rocks, and can only be determined with absolute certainty by the completion of the mapping, the investigations so far indicate that in the region in question the Hastings series would seem to represent the Grenville series in a less altered form. In other words, the Hastings series, when invaded, disintegrated, fretted away and intensely metamorphosed by and mixed up with the underlying magma of the Fundamental Gneiss, constitutes what has elsewhere been termed the Grenville series. The Grenville series may, however, represent only a portion of the Hastings series, and the work so far done in this district has not been sufficient to determine the stratigraphical position of this portion.

Concerning the age of the Hastings series but little is known as yet. To the southeast of the area under consideration, however, its clastic character is well marked, breccias and conglomerates, often greatly deformed by pressure, being present as well as certain fine-grained and comparatively unaltered limestones, in which a very careful search may yet be rewarded by the discovery of fossils. Both lithologically and stratigraphically the rocks bear a striking resemblance to rocks mapped as Huronian in the region to the north and northeast of Lake Huron, and it seems very likely that the identity of the two series may eventually be established. The two areas, however, are rather widely separated geographically, so that the greatest care will have to be exercised in attempting such a correlation.

Like the Grenville series, the rocks of the Hastings series are unconformably overlain by and disappear beneath the flatlying Cambro-Silurian rocks of the plains, which limit the protaxis on the south and are separated from it in time by an immense erosion interval. Further investigation in this area, as well as in that adjoining to the east, now being mapped by Dr. R. W. Ells, will, however, it is hoped, before long throw additional light on the age of this very interesting and important series of rocks. If further investigation proves that the relations of the several series have been correctly diagnosed,

and that the explanation of these relations as given above is correct, the Laurentian system of Logan will resolve itself into an enormous area of the Fundamental Gneiss, which is essentially of igneous origin and which there is every reason to believe forms part of the downward extension of the original crust of our planet, perhaps many times remelted and certainly in many places penetrated by enormous intrusions of later date; into which Fundamental Gneiss, when in a softened condition, there have sunk portions of an overlying series, consisting chiefly of limestones.

Farther east, in that portion of the province of Quebec where the Grenville series was first studied by Logan, the rocks of the Hastings series proper have not been recognized. The Lower Paleozoic strata rest directly upon the Grenville series and would cover up the Hastings series to the south should it extend as far east as this. The limestones of the Grenville series, moreover, here extend much farther back from the edge of the protaxis in bands and streaks conforming to the strike of the underlying gneissic rocks, so that the origin of the series and its relations to the Fundamental Gneiss is not so clearly indicated. When, however, its relations here are interpreted in the light of the Ontario occurrences, there seems to be no reason why the same explanation might not be offered to account for its origin also. The bands of limestone, which often vary in thickness from place to place, and are frequently interrupted in their course or abruptly cut off, might be considered as having taken their form from long folds in the series from which they were derived as it settled down into the magma beneath, or as having been separated by great lateral intrusions of the gneissic magma. Their original shape and character has, however, without doubt been greatly altered by the enormous movements to which both series of rocks have been subsequently subjected.

If again this proves to be the true explanation of the relations of these series, the Grenville series will cease to be an anomaly among our Archæan formations and will, so far as its mode of occurrence is concerned, bear the same relation to the Fundamental Gneiss as the Huronian does farther west in the Lake Superior and Huron district, as shown by Lawson and Barlow; the similarity in position, however, not implying identity in age.

The recognition of the Grenville series as consisting of a series of sedimentary rocks, largely limestones, invaded by igneous material which now makes up by far the greater portion of the series and consists largely of extravasations of the Fundamental Gneiss, is now pretty certainly established by the field evidence. Its recognition as a portion of the Hastings series which has been intensely metamorphosed, will probably be more clearly established as the field work progresses. Since subordinate areas of the Grenville series also occur to the

south of the St. Lawrence in the Adirondack region, and are now being mapped, it will be of great interest to ascertain whether the same relations do not also exist in that area, and whether a continuation of the Hastings series to the south cannot be recognized in the "Huronian Schist" of St. Lawrence and Jefferson counties, shown upon the Geological Map of the State of New York, which has just been issued by the Geological Survey of this State.

It is perhaps unnecessary to draw attention to the fact that the recent investigations of Messrs. Wolff, Brooks, Nason, Kemp, Westgate and others on the crystalline limestones of New Jersey have a certain bearing on this subject.

Remarks by R. W. Ells:

In connection with the statements advanced in the preceding paper by Dr. Adams and Mr. Barlow, it is but right that the conclusions arrived at from the study of the similar rocks in their eastern and northern extension should be stated. The investigations in this quarter have now been carried on for six years, and have extended over a very large area to the north of the Ottawa, in which is included the typical Grenville series of Sir W. E. Logan, and extending far up the Gatineau River; while to the westward, the work has been carried on till the vicinity of the area, described in the accompanying paper, has been reached. It may be said therefore that the detailed examination of the rocks which make up the Grenville and Hastings series has extended over an area about 250 miles in length by 75 miles in breadth.

In the early days of the study of these rocks much difficulty was experienced. Firstly there was a great and almost inaccessible wilderness, the only available means of travel over the greater portion being by canoes; and in the second place there was an almost entire lack of trained observers to carry on the work. Add to this the entire absence of microscopical determinations, and one can readily comprehend the difficulty experienced in the attempt to solve this most difficult of the problems in Canadian geology.

Foliation and stratification were considered conclusive evidence of sedimentation, and as most of the rocks of the great Laurentian complex gave evidence of these forms of structure, the inference naturally followed that the greater portion of the gneissic, granitic and anorthositic rocks were of sedimentary origin. So far was this sedimentary theory carried out that, in the earlier reports of the Geological Survey, even the masses of binary granite and many of the pyroxenic rocks were included in the same category. This was at the time a very natural conclusion, since many of these masses have a regular bedded structure and conform, over very considerable areas, to the regular stratification of the rocks, either gneiss or crystalline limestone. As the country became more accessible the

field investigations showed very clearly the intrusive nature and later age of many of these masses, while the aid of the microscope fully established the non-clastic and igneous character of the great bulk of the gneisses. The more recent and probably sedimentary origin of the limestones and associated gneisses of the Grenville series, as distinct from the great mass of the underlying Laurentian Fundamental Gneiss, was pointed out some years ago in a paper by the author, read before the Geological Society of America. The subsequent investigations on these rocks, to the west and southwest, showed that the conclusions then presented were correct, but that as the work extended westward to the south side of the Ottawa the character of the various groups of rocks gradually changed. The areas of limestone became much more extensive, and there was a large development of hornblende and other dark-colored rocks, rarely seen to the north of the Ottawa. The limestones also were very often highly dolomitic, and in certain areas were blue and slaty, with but little of the aspect of the Grenville limestones, except where they were in close contact with masses of intrusive granite or diorite. There is also in the rocks of this group to the south of the Ottawa, where they have been styled the Hastings series, from the fact that they were first studied in the county of Hastings, a very considerable proportion of schists, micaceous, chloritic and hornblendic, with certain regularly slaty beds, and others of true conglomerate containing quartz pebbles. In certain portions the lithological resemblances between the Grenville and Hastings rocks are very close, and they may, for all practical purposes, be regarded as one and the same series. From a number of sections made in the counties of Renfrew on the south of the Ottawa, and in Pontiac, to the north of that river, it would appear that the original Grenville limestones and associated grey and rusty gneiss form the lower part of the series, since it is only on their development westward towards the typical Hastings locality that the characteristic Hastings schists and associated strata are met with.

In character and general aspect these rocks of the Hastings series are almost identical with many of those which in the Eastern Townships and in New Brunswick have been regarded as probably Huronian for many years; and so marked is the resemblance that the author, in presenting his summary report for 1894, referred the rocks seen near the Bristol iron mines to that division. It now appears very conclusively established that both in the eastern and western areas we have a well developed series of rocks, including limestones, gneiss and schists, which are of undoubted sedimentary origin, but which have been enormously acted upon by great intrusive masses as well as by other dynamic agencies, so that in many parts their original characters have almost entirely disappeared.

ART. XVIII.—*Outline of a Natural Classification of the Trilobites;* by CHARLES E. BEECHER. (With Plate III.)

[Continued from page 106.]

Arrangement of the Families of Trilobites.

SUBCLASS TRILOBITA.

Order A. HYPOPARIA.

Family 1. Agnostidæ.
Family 2. Harpedidæ.
Family 3. Trinucleidæ.

Order B. OPISTHOPARIA.

Family 4. Conocoryphidæ.
Family 5. Olenidæ.
Family 6. Asaphidæ.
Family 7. Proëtidæ.
Family 8. Bronteidæ.
Family 9. Lichadidæ.
Family 10. Acidaspidæ.

Order C. PROPARIA.

Family 11. Encrinuridæ.
Family 12. Calymenidæ.
Family 13. Cheiruridæ.
Family 14. Phacopidæ.

The order Opisthoparia, with nearly one hundred and fifty genera, has a much greater geological distribution than either of the others, and was by far the dominant group during the Cambrian and Ordovician, being represented by about eighty-five genera in the former age and forty-five in the latter. Nineteen genera of this order are found in the Silurian and ten in the Devonian, most of them having continued on from older ages. Four genera represent the order in the Carboniferous and one in the Permian, thus marking the extinction of the subclass as well as the last genera of the Opisthoparia.

The comparative abundance and duration of the three orders are expressed in the table on page 182, from which it appears that the Hypoparia probably culminated in pre-Cambrian times, the Opisthoparia during the Cambrian, and the Proparia during the Ordovician.

In the following classification, the families adopted by Salter[34] and Barrande[3] are in the main adhered to, and the number corresponds very closely with that in Zittel's "Handbuch der Palæontologie"[35] and also in the "Grundzüge"[36] of the same author. The order of arrangement, however, is very different. A great number of family divisions have been proposed, and undoubtedly many others will yet be made, but it is not within the province of this paper to determine the precise value and

limitations of the families. This would require discussions of priority and synonymy, and otherwise detract from the direct purpose of the writer; viz., to establish a basis for a natural classification, and in this way to apply what is currently known and accepted regarding the trilobites. Nevertheless, some notice must be taken of several families and genera which for various reasons do not appear here. The family Aglaspidæ, including the genus *Aglaspis* Hall, proves to belong to the Merostomata, and is therefore omitted. The family Bohemillidæ has been shown by the writer[6] to have no foundation, because the type of the genus *Bohemilla* Barrande was based upon a mutilated specimen of *Æglina*.

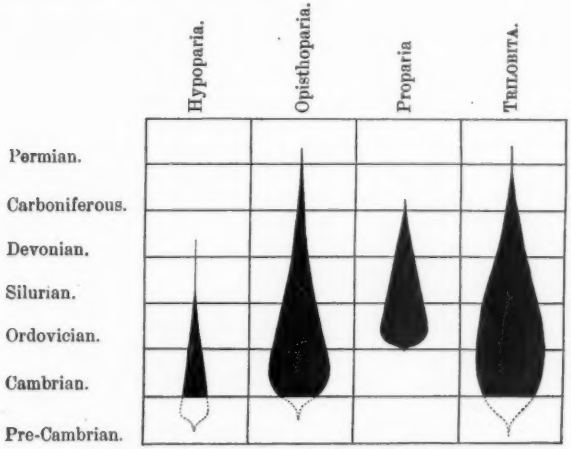

Table of Geological Distribution of Trilobites.

Several genera still commonly adopted are not here recognized in the lists under the families, since from the minute size of the individuals described and their immature characters, they must be considered as the young of larger forms. Such are *Conophrys* Callaway, *Cyphoniscus* Salter, *Holometopus* Angelin, *Isocolus* Angelin, and *Shumardia* Billings. *Triopus* Barrande has been shown to be a chiton.

Much could be said against some of the recognized genera, but, as with the families, the writer has preferred in almost every case to adopt, for the present, what has been commonly accepted, and thus to avoid the entanglements of dates and synonyms which would be out of place in any general discussions. The type species of every genus is here made the central idea. It is taken as representing the genus more closely than any fortuitous assemblage of diverse species, which the

next investigator may show belong to another or to several genera. Our ideas of a genus are naturally based mainly upon the species with which we are most familiar. Until forced to make authoritative comparative statements, it does not occur to one that the type of the genus under consideration may be quite different. An American student's conception of *Homalonotus* will probably be formed largely upon the species commonly known as *H. delphinocephalus* Green, from the Niagara, and *H. DeKayi* Green, from the Hamilton. The first time the type of the genus, *H. Knighti* Murchison, is seen he will be puzzled to place it. Similar examples could be multiplied indefinitely, and only show that the type must be taken as the ultimate unit of comparison.

Diagnoses and Discussions of Orders and Families.

Order A. HYPOPARIA, n. ord.

(ὑπό under, and πᾶρειά cheek piece.)

Free cheeks forming a continuous marginal ventral plate of the cephalon, and in some forms also extending over the dorsal side at the genal angles. Suture ventral, marginal, or submarginal. Compound paired eyes absent; simple eyes may occur on each fixed cheek, singly or in pairs.

Including the families Agnostidæ, Harpedidæ, and Trinucleidæ.

This order includes the groups C and D, or the *Ampycini* and *Agnostini* of Salter, and also the family Harpedidæ of that author, which he included in the *Asaphini*. The special recognition of characters, however, between Salter's groups and the order here proposed is different.

The presence of a part homologous with the free cheeks of other trilobites has generally been more or less overlooked in the families of this order. In *Trinucleus*, *Dionide*, and *Harpes*, the sutures have been correctly determined by Barrande.[2] Likewise, Angelin[3] gave the right structure in *Ampyx*, but in *Agnostus*, this feature has escaped notice. The examination of extensive series of *Agnostus*, in the National Museum and in the Museum of Comparative Zoölogy,* has proved that under favorable conditions of preservation this genus shows a distinct plate, separated from the cranidium by a suture, and it can be compared only with the free cheeks in other trilobites,

* In the former, through the courtesy of C. D. Walcott and C. Schuchert, and in the latter, of A. Agassiz and R. T. Jackson.

especially where they are continuous around the front of the cephalon, as in *Trinucleus* and *Ampyx*. The presence of a hypostoma in *Agnostus* was also determined. Even in the higher genera of this order, the suture is frequently unnoticed in descriptions, but it can be seen in all well-preserved specimens. In *Trinucleus*[28] and *Harpes*, it follows the edge of the cephalon, and separates the dorsal from the ventral plate of the pitted limb. Since eye spots occur on the fixed cheeks in the young *Trinucleus* and adult *Harpes*, it is probable that this character is a primitive one in this order, and has been lost in *Agnostus*, *Microdiscus*, *Ampyx*, and *Dionide*.

The ontogeny of *Sao*, *Ptychoparia*, *Triarthrus*, *Dalmanites*, etc., shows that the true eyes and free cheeks are first developed ventrally, appearing later at the margin, and then on the dorsal side of the cephalon. Therefore, the Agnostidæ, Trinucleidæ, and Harpedidæ have a very primitive head structure, characteristic of the early larval forms of higher families. Other secondary features show that this order, though the most primitive in many respects, is more specialized that either of the others, except in their highest genera. The characters referred to are the glabella and pygidium. Very few species show the primitive segmentation of the glabella, it being usually smooth and inflated, and resembling in its specialization such higher genera as *Proëtus*, *Asaphus*, and *Lichas*. The pygidium often fails to indicate its true number of segments. Some *Agnostus* and *Microdiscus* show no segments either on the axis or limb of the pygidium. *Trinucleus* and others may have a many annulated axis and fewer grooves on the pleural portions. The number of appendages corresponds to the axial divisions, as determined by the writer.[4] The multiplication of segments in the pygidium and their consequent crowding makes them quite rudimentary.

Family I. Agnostidæ Dalman.

Small forms, having the cephalon and pygidium elongate, nearly equal, and similar in form and markings. Free cheeks ventral, continuous; suture marginal or ventral. Eyes wanting. Thorax composed of from two to four segments, with grooved pleura. Cambrian and Ordovician.

Including the genera *Agnostus* Brongniart, and *Microdiscus* Emmons.

The genera in this family are primitive in their form and structure, as shown by their ventral free cheeks, marginal or ventral suture, elongate cephalon, and large pygidium. Some

species have spines at the genal angles, corresponding to the interocular spines of *Holmia*, and young *Elliptocephala*, and not to the spiniform projections of the free cheeks. From their abbreviated thorax, and progressive loss of annulations on the glabella and axis of the pygidium, they must also be considered as degraded. *Microdiscus*, the earlier genus, has three or four free segments, and in some species (*M. speciosus* Ford) preserves the normal pentamerous glabella and annulated pygidial axis, while the later genus, *Agnostus*, has but two free segments, and has lost the annulations of both glabella and pygidium. Matthew[26] has described the protaspis stage of *Microdiscus*, which agrees with the similar stage of *Ptychoparia* and *Sao*.

Fully a dozen generic names have been proposed for forms of the general type of *Agnostus*, but none of them has ever come into current use. Nine were first published by Corda,[15] but as Barrande[3] subsequently showed that one was based on an *Orbicula*, another on a poor specimen of *Æglina*, and three others on a single species, this grouping soon fell into disuse. Moreover, Barrande was inclined to give no generic value to the form and lobation of the glabella, and therefore all the species were placed by him in the single genus *Agnostus*. At the present time, more weight is given to the characters of the glabella and pygidium, as indicating generic differences in dorsal and ventral structure, so that further study may show the desirability of restoring such of Corda's names as were founded upon natural groups of this family.

Family II. Harpedidæ Barrande.

Cephalon large, margined by a broad expansion or limb; glabella short and prominent. Free cheeks ventral, continuous; suture marginal, following the outer edge of the limb. Paired simple eye spots, or ocelli, single or double, at the distal ends of well-marked eye lines on the fixed cheeks, extending outward from the glabella. Thorax of from twenty-five to twenty-nine segments, with long grooved pleura. Pygidium (in *Harpes*) very small, composed of but three or four segments. Cambrian to Devonian.

Including *Harpes* Goldfuss, *Harpina* Novák, and *Harpides*? Beyrich.

The genus *Harpes* presents considerable variation in the lobes of the glabella. *H. ungula* Sternberg shows the full number of five lobes, but in some species, as *H. d'Orbignyianum*

Barrande, the structure is like *Cyphaspis*, with separate basal lobes. *Arraphus* Angelin was apparently based upon a specimen of *Harpes* denuded of the pitted border. *Harpides* Beyrich is imperfectly known but seems to belong here. The ocular ridges and tubercles on the fixed cheeks, the broad limb, the glabella, and the narrow weak thoracic segments are all in accord with *Harpes*, though in other features it has affinities with the Conocoryphidæ.

In many respects, *Harpes* is one of the most interesting genera of trilobites since it is so unlike other forms. The broad hippocrepian pitted limb of the cephalon has its counterpart in *Trinucleus* and *Dionide*, although not so well developed in these genera. The head is also comparatively longer and larger, both features being decidedly larval. It is the only family known in which functional visual spots, or ocelli, are situated on the fixed cheeks. The young *Trinucleus* has similar eye spots, or ocelli. The great number of free segments in the Harpedidæ is another primitive character, although the cephalon (in *Harpes*) still remains larger than the thorax and pygidium.

Family III. Trinucleidæ Barrande.

Cephalon larger than the thorax or pygidium; genal angles produced into spines. Free cheeks continuous, almost wholly ventral, carrying the genal spines; suture marginal or submarginal. Paired simple eyes or ocelli generally absent in adult forms; compound eyes wanting. Segments of thorax five or six in number, with grooved pleura. Pygidium triangular; margin entire; axis with a number of annulations; limb grooved. Ordovician and Silurian.

Including the genera and subgenera *Trinucleus* Lhwyd, *Ampyx* Dalman, *Dionide* Barrande, *Endymionia* ? Billings, *Lonchodomus* Angelin, *Raphiophorus* Angelin, and *Salteria* ? W. Thompson.

The leading genera of this family form a tolerably homogeneous group, although each has sometimes been recognized as characterizing a separate family. *Trinucleus* and *Dionide* have a broad pitted border, but this hardly seems of sufficient importance to remove them far from *Ampyx*, since the three genera agree in nearly all important structural details, as the extent and character of the free cheeks, the glabella, the number of free segments, and the character of the pygidium. *Lonchodomus* and *Raphiophorus* of Angelin are commonly admitted as subgenera of *Ampyx*.

Both *Salteria* W. Thompson and *Endymionia* Billings have been described as subgenera of *Dionide* Barrande, though there is little positive evidence for this disposition of them. Until more perfect material representing these forms has been described, it will not be possible to decide satisfactorily upon their relationships or place in a classification. Therefore, they are left with doubt in the present family.

Order B. OPISTHOPARIA, n. ord.

(ὄπισθε behind, and πᾶρειά cheek piece.)

Free cheeks generally separate, always bearing the genal angles. Facial sutures extending forwards from the posterior part of the cephalon within the genal angles, and cutting the anterior margin separately, or rarely uniting in front of the glabella. Compound paired holochroal eyes on free cheeks, and well developed in all but the most primitive family.

Including the families Conocoryphidæ, Olenidæ, Asaphidæ, Proëtidæ, Bronteidæ, Lichadidæ, and Acidaspidæ.

This order is nearly equivalent to group B, or the *Asaphini* of Salter, which included also the families Calymenidæ and Harpedidæ, which belong elsewhere.

The families which are here placed under this order lend themselves quite readily to an arrangement based upon the characters successively appearing in the ontogeny of any of the higher forms. Thus *Sao*, *Ptychoparia*, and other genera of the Olenidæ have first a protaspis stage only comparable in the structure of the cephalon with the genera of the preceding order, the Hypoparia. Therefore this stage does not enter into consideration in an arrangement of the families of the Opisthoparia. In the later stages, however, there is a direct agreement of structure with the lower genera of this order. The nepionic *Sao*, with two thoracic segments (Plate III, fig. 2), has a head structure agreeing in essential features with that in *Atops* or *Conocoryphe* (Plate III, figs. 14, 15). A later nepionic stage, with eight thoracic segments (Plate III, fig. 3), agrees closely with adult *Ptychoparia* or *Olenus* (figs. 16, 17). These facts clearly indicate that the family Conocoryphidæ should be put at the base of this extensive order. Then, as *Ptychoparia* and *Olenus* are more primitive and simple genera than *Sao*, they, as typifying the family Olenidæ, should govern its position, which accordingly would be next after the Conocoryphidæ. In each case, a family is considered as represented by its typical and most characteristic forms. It would be impossible to

consider the advanced specialized genera of some families as representing their normal facies, for each one has undergone an independent evolution, and some characters have reached as great a degree of differentiation as will be found in much higher families.

It has been recognized that variations in the positions of the eyes, the relative size of the free and fixed cheeks, and the degree of specialization of the glabella have a definite order in the ontogeny of any trilobite, and also that these characters have a greater taxonomic value than many others. Applying these principles in arranging the families which come under the Opisthoparia, we have the sequence as indicated above, beginning with the Conocoryphidæ and followed by the Olenidæ, Asaphidæ, Proëtidæ, Bronteidæ, Lichadidæ, and Acidaspidæ, in regular progression. See Plate III, figs. 14–23.

Family IV. Conocoryphidæ Angelin.

Free cheeks very narrow, forming the lateral margins of the cephalon, and bearing the genal spines. Fixed cheeks large, usually traversed by an eye line extending from near the anterior end of the glabella. Facial sutures running from just within the genal angles, curving forward, and cutting the anterior lateral margins of the cephalon. Eyes rudimentary or absent. Thorax with from fourteen to seventeen segments. Pygidium small and of few segments. Cambrian.

Including the genera and subgenera *Conocoryphe* Corda (=*Conocephalites* Barrande), *Aneucanthus* Angelin, *Atops* Emmons, *Avalonia* Walcott, *Bailiella* Matthew (=*Salteria* Walcott and *Erinnys* Salter), *Bathynotus* Hall, *Carausia* Hicks, *Carmon* Barrande, *Ctenocephalus* Corda, *Dictyocephalites* Bergeron, *Eryx* Angelin, *Harttia* Walcott, and *Toxotis* Wallerius.

The genera coming under this family present a number of very primitive characters such as are shown only in the larval stages of higher forms. The free cheeks are narrow and marginal, and can be compared with those in the nepionic stages of *Sao* and *Ptychoparia*. The eyes have not been detected, but the presence of an eye line suggests their possible existence. The variations of the glabella are very marked, and are as great as those which in higher forms attain some importance as family characteristics. In *Toxotis*, *Carausia*, and *Aneucanthus*, the glabella expands in front, joining and forming part of the anterior margin, as in the glabella of the larval stages of *Solen-*

opleura, *Liostracus*, *Ptychoparia*, and *Sao*. *Ctenocephalus* and *Eryx* are slightly more advanced, as the glabella no longer marks the edge of the cephalon. In *Atops*,* *Avalonia*, *Bathynotus*, and *Carmon*, the glabella is cylindrical, distinctly defined, and limited within the margin, and in *Conocoryphe*, *Harttia*, and *Bailiella*, it narrows anteriorly, and only extends about two-thirds the length of the head. Generally in this family, the glabella displays its primitive pentamerous origin. In *Bailiella* and *Carausia*, two basal lobes are marked off from the fourth segment by oblique furrows, as in *Proëtus* and *Cyphaspis*.

From a phylogenetic standpoint, the family Conocoryphidæ is at the base of this extensive order. As far as known, all the larval forms in the other families of the Opisthoparia agree in having the narrow marginal free cheeks, bearing the genal angles. The eye line is present in most of the adult Olenidæ, and in the early stages of all as far as known, so that the general average of the characters in the Conocoryphidæ represents the main larval features throughout the other families. They show, too, that although primitive in essential structure, differentiation through time has developed secondary features belonging to genera in higher families, as, for example, the basal glabellar lobes in *Bailiella*.

Family V. Olenidæ Salter.

Cephalon larger than the pygidium, usually wider than long; genal angles commonly produced into spines. Free cheeks separate. Facial sutures extending forward from the posterior margin of the cephalon along the eye lobes, and either cutting the anterior margin separately or meeting on the median line. Eyes crescentic, reniform, or semicircular, situated at the ends of eye lines in all but highest genera. Trunk long, composed of from eight (?) to twenty-six free segments; rarely capable of rolling up. Pygidium frequently small; margin entire or spinose.

Principally Cambrian, but extending into the Ordovician.

Including the genus *Olenus* Dalman as the type, and the following genera and subgenera, which should doubtless fall into several subfamily or even family groups: *Acerocare* Angelin, *Acrocephalites* Wallerius, *Agraulus* Corda, *Angelina* Salter, *Anomocare* Angelin, *Anopolenus* Salter, *Asaphe-*

* *Atops* (type *A. trilineatus* Emmons) seems to be a valid genus, and differs from *Conocoryphe* (type *C. Sulzeri* Schlotheim) in its glabellar characters, greater number of thoracic segments, and much smaller pygidium with fewer segments.

lina Bergeron, *Bavarilla* Barrande, *Bergeronia* Matthew, *Boeckia* Brögger, *Ceratopyge* Corda, *Chariocephalus* Hall, *Corynexochus* Angelin, *Crepicephalus* Owen, *Ctenopyge* Linnarsson, *Cyclognathus* Linnarsson, *Dikelocephalus* Owen (*Centropleura* Angelin), *Dorypyge* Dames, *Ellipsocephalus* Zenker, *Elliptocephala* Emmons, *Euloma* Angelin, *Eurycare* Angelin, *Holmia* Matthew, *Hydrocephalus* Barrande (=young *Paradoxides*), *Leptoplastus* Angelin, *Liostracus* Angelin, *Loganellus* Devine, *Menocephalus* Owen, *Mesonacis* Walcott, *Micmacca* Matthew, *Neseuretus* Hicks, *Olenelloides* Peach, *Olenellus* Hall, *Olenoides* Meek, *Oryctocephalus* Walcott, *Palæopyge* Salter, *Parabolina* Salter, *Parabolinella* Brögger, *Paradoxides* Brongniart, *Peltura* Angelin, *Plutonides* Hicks, *Proceratopyge* Wallerius, *Protagraulus* Matthew, *Protolenus* Matthew, *Protopeltura* Brögger, *Protypus* Walcott, *Pterocephalia* Roemer, *Ptychaspis* Hall, *Ptychoparia* Corda, *Remopleurides* Portlock, *Sao* Barrande, *Schmidtia* Marcou, *Solenopleura* Angelin, *Sphæropthalmus* Angelin, *Telephus* Barrande, *Triarthrella* Hall, *Triarthrus* Green, and *Zacanthoides* Walcott.

A complete study of this extensive family of trilobites would contribute much in the way of generic synonymy, and bring out the characters necessary for family determination and subdivision. This important work must be left for future investigation. So many genera have been described from separate cranidia or even pygidia as to make it impossible to deal with all of them in a systematic manner. The zeal to make the most out of the earliest known faunas has led many investigators to describe and recognize imperfect and poorly preserved material, and to establish genera upon very tenuous characters. Therefore, without a most intimate knowledge of all the forms, any grouping of the majority of the Cambrian genera into families or the limitations of the genera themselves must, as in the present instance, be taken tentatively and as necessarily incomplete.

A number of genera have already been made the types of family divisions, as *Paradoxides*, *Olenellus*, *Remopleurides*, *Ellipsocephalus*, *Ptychoparia*, etc. Some of them may be shown ultimately to possess characters of sufficient weight to be entitled to family distinction. A preliminary grouping of the best known genera may be of some value here, and for the sake of convenience, these divisions may be defined as subfamilies. Four groups will be recognized, of which *Paradoxides*, *Oryctocephalus*, *Olenus*, and *Dikelocephalus* are taken as representative genera.

I. *Paradoxinæ.* Including *Olenellus*, *Holmia*, *Mesonacis*, *Elliptocephala*, *Schmidtia*, *Olenelloides*, *Paradoxides*, *Zacanthoides*, and *Remopleurides*. Most of the genera are distinguished by their long narrow eyes, often extending more than half the length of the glabella, but more especially by the rudimentary character of the pygidium. In *Olenellus*, the pygidium is a long telson-like spine. In *Holmia*, *Mesonacis*, *Elliptocephala*, and *Schmidtia*, it is reduced to a small plate without distinct segmental divisions. In *Paradoxides*, *Zacanthoides*, and *Remopleurides*, the axis may show from one to five annulations, while the limb may carry two or three pairs of spines or may be entire. In *Olenellus* and *Holmia*, true facial sutures have been denied by some authors, but in their place false sutures are recognized. They are, however, evidently real sutures in a condition of symphysis, which often occurs in *Phacops*, *Proëtus*, *Phillipsia*, etc. Otherwise, these genera would violate the first principle of trilobite structure, in not having the compound eyes on the free cheek pieces. *Olenelloides* is a very striking form, but its pygidium is unknown, and the head structure is obscure. The elongate cephalon is a decidedly larval feature, and the genal and interocular (?) spines strongly suggest its immature condition, and point to the possibility of its being the young of *Olenellus* or a related form.

There has been much discussion as to the synonymy and value of most of the names proposed as genera or subgenera in this group. *Paradoxides*, *Remopleurides*, and *Zacanthoides* are about the only ones that have escaped severe criticism in recent years. Taking the type of each of the others, it is found that *Elliptocephala* (1844) was based on the species *E. asaphoides* Emmons, *Olenellus* (1862) on *O. Thompsoni* Hall, *Mesonacis* (1885) on *M. vermontana* Hall sp., *Holmia* (1890) on *H. Kjerulfi* Linnarsson sp., *Schmidtia* (1890) on *S. Mickwitzi* Schmidt sp., and *Olenelloides* (1894) on *O. armatus* Peach. Some of these names are generally recognized as subgenera of *Olenellus* (*Mesonacis*, *Holmia*, *Olenelloides*), while others are considered as synonyms (*Elliptocephala*, *Schmidtia*). The early genera were described from very incomplete material, and therefore lacked sufficient diagnostic characters to clearly define them. At the present time, nearly or quite entire specimens representing the type species are known, and it is possible to compare all the essential features with some degree of accuracy. The main characters offering the greatest variation are (1) the number of thoracic segments and (2) their specialization into groups, (3) the relative development of the third free segment, (4) the number and position of the spine-bearing segments, (5) the form of the pygidium,

(6) the presence or absence of interocular spines, and (7) the form of the cephalon. A simple variation in any one of these would not necessarily imply more than a specific difference, but the genera here mentioned exhibit marked changes in all or nearly all of these characters, and in any family should receive recognition. *Olenellus*, *Mesonacis*, and *Elliptocephala* are more closely related than the other forms, and probably have only a subgeneric value under *Elliptocephala*. In the first form with fourteen thoracic segments, the third is greatly enlarged and the fifteenth is the spiniform, telson-like pygidium. In *Mesonacis* with twenty-six thoracic segments, the third is somewhat enlarged, and behind the narrow spine-bearing fifteenth segment there are eleven others without spines, followed by the small plate-like pygidium. In *Elliptocephala* with eighteen thoracic segments, the cephalon is broader, the third segment is not enlarged except in the young, and the fourteenth to eighteenth segments are narrower and spine-bearing.

II. *Oryctocephalinæ*. Including *Oryctocephalus*, *Ctenopyge*, *Olenoides*, and *Parabolina*, with large pygidia and all but the last one or two pleural elements continued into spines; also *Eurycare*, *Angelina*, *Peltura*, and *Protopeltura*, with smaller and shorter pygidia and denticulations of the margins corresponding to the pleural divisions.

III. *Oleninæ*. Including *Olenus*, *Agraulus*, *Liostracus*, *Acerocare*, *Ptychoparia*, *Solenopleura*, *Ptychaspis*, *Leptoplastus*, *Loganellus*, *Sphæropthalmus*, *Parabolinella*, *Boeckia*, *Proceratopyge*, *Ceratopyge*, *Protypus*, *Ellipsocephalus*, *Sao*, and *Triarthrus*. All these genera have small or medium-sized pygidia, with from two to eight annulations in the axis. Eyes medium to small, at the ends of distinct eye lines in all but the latest genera, which preserve this character only during the young stages. Thoracic segments from eleven to eighteen.

IV. *Dikelocephalinæ*. Including *Dikelocephalus*, *Asaphelina*, and *Crepicephalus*. Eight or nine thoracic segments. Pygidium wide, with the posterior lateral portion often produced into broad spine-like extensions. *Dikelocephalus* is in many ways related to *Ogygia* and *Asaphus*.

Family VI. Asaphidæ Emmrich.

Cephalon and pygidium well developed; glabella often obscurely limited. Free cheeks usually separate. Facial sutures extending forward from the posterior edge of the cephalon within the genal angles, and cutting the lateral or anterior margins, occasionally uniting in front of the glabella.

Eyes smooth, well developed, sometimes of very large size, even occupying the entire surface of the free cheeks. Thorax generally composed of eight or ten segments, but varying from five to ten; capable of enrollment. Pygidium large, often with wide doublure.

Cambrian, Ordovician, and Silurian.

The long list of genera in this family may easily be divided into two sections, which are often recognized as of family rank.

I. ASAPHIDÆ. Including the genera and subgenera *Asaphus* Brongniart (=*Cryptonymus* Eichwald), *Asaphellus* Callaway, *Asaphiscus* Meek, *Barrandia* McCoy, *Basilicus* Salter, *Bathyurellus* Billings, *Bathyuriscus* Meek, *Bathyurus* Billings, *Bolbocephalus* Whitfield, *Brachyaspis* Salter, *Bronteopsis* W. Thompson, *Dolichometopus* Angelin, *Gerasaphes* Clarke, *Holasaphus* Matthew, *Homalopecten* Salter, *Isotelus* DeKay, *Megalaspides* Brögger, *Megalaspis* Angelin, *Niobe* Angelin, *Ogygia* Brongniart, *Ogygiopsis* Walcott, *Phillipsinella* Novák, *Platypeltis* Callaway, *Ptychopyge* Angelin, and *Stygina* Salter.

This is a tolerably homogeneous group, although some of the Cambrian forms have a sufficiently archaic expression to make them seem a little out of place with genera of so pronounced a family type as *Asaphus*, *Niobe*, *Ptychopyge*, *Megalaspis*, and *Isotelus*.

The elements of the glabella are generally quite obscure, and even its limits cannot be clearly made out in late genera, as *Stygina* and *Asaphus*. The segmental nature of the glabella is clearly shown in *Ogygia*, *Ogygiopsis*, *Homalopecten*, *Asaphellus*, *Bronteopsis*, and *Bathyuriscus*.

The elements of the pygidium are obscurely marked in *Brachyaspis* and *Isotelus*. *Phillipsinella* is a very small form, and probably the young of an *Asaphus*. *Barrandia*, *Homalopecten*, and *Stygina* serve as transition genera to the Illænidæ.

II. ILLÆNIDÆ. Including the genera and subgenera *Illænus* Dalman, *Æglina* Barrande (=*Cyclopyge* Corda), *Bumastus* Murchison, *Dysplanus* Burmeister, *Ectillænus* Salter, *Holocephalina* Salter, *Hydrolenus* Salter, *Illænopsis* Salter, *Illænurus* Hall, *Nileus* Dalman, *Octillænus* Salter, *Panderia* Volborth, *Psilocephalus* Salter, *Symphysurus* Goldfuss, and *Thaleops* Conrad.

The Illænidæ form a much more compact group than the preceding, characterized by having an epistomal plate and by

the very tumid form of the large cephalon and the obscure or obsolete boundaries of the glabella and occipital lobe. The pygidium often closely resembles the cephalon in size and form, and the axis is frequently scarcely defined.

Considerable variation is shown in the size, position, and direction of the visual surfaces. There is also a ratio between the size of the fixed cheeks and the eyes. In proportion as the fixed cheeks are large, the eyes are small, and as the area of the fixed cheeks diminishes from a widening of the axis of the animal, the eyes become larger. Thus, in *Holocephalina*, with extremely large fixed cheeks and narrow axis, the eyes are quite small. In *Illænopsis*, *Dysplanus*, *Panderia*, and *Octillænus*, they are progressively larger, and in *Illænus*, *Bumastus*, and *Nileus*, where the axis is wide and the fixed cheeks reduced, the eyes are relatively large. This variation reaches its limit in the species of *Æglina*, where the axis is very wide and the fixed cheeks are reduced to almost nothing, so that the glabella and eyes make up the entire dorsal surface of the cephalon. In *Æglina princeps* Barrande, the eyes extend about half the length of the cephalon. The eyes of *Æ. rediviva* Barr. bound the whole length of the sides of the head, and in *Æ. armata* Barr., the coalesced free cheek pieces are almost wholly converted into a visual area, so that there is a continuous eye around the sides and front of the head.

Variations in the position of the eyes are to be noted in nearly all the genera. In *Ectillænus* and *Psilocephalus*, they are in front of the middle of the length of the cephalon, and in *Dysplanus*, *Illænopsis*, and *Holocephalina*, they are near the posterior angles of the cranidium. *Panderia* has the eyes directed obliquely backward, and in *Thaleops*, they are carried on conical extensions pointing outwards.

Family VII. Proëtidæ Barrande.

Cephalon about one-third of the whole animal; genal angles generally produced into spines; glabella tumid, with two lateral basal lobes defined by oblique furrows in front of the neck segment. Free cheeks large, separate. Sutures extending from the posterior margin inward to the eyes, and then forward, cutting the anterior margins separately. Eyes prominent, often large. Thorax of from eight to twenty-two free segments, with grooved pleura. Pygidium usually of many segments; pleural and axial portions strongly grooved; margin entire or dentate. Ordovician to Permian.

Including the genera and subgenera *Proëtus* Steininger,

Arethusina Barrande, *Brachymetopus* McCoy, *Celmus* Angelin, *Cordania* Clarke, *Crotalurus* Volborth, *Cyphaspis* Burmeister, *Dechenella* Kayser, *Griffithides* Portlock, *Phaëtonella* Novák, *Phillipsia* Portlock, *Prionopeltis* Corda, *Pseudophillipsia* Gemmellaro, *Schmidtella* Tschernyschew, *Tropidocoryphe* Novák, and *Xiphogomium* Corda.

The genera of this family readily fall into a series expressing more or less closely the development and specialization of various characters. *Arethusina* is the only genus retaining the archaic eye lines, and both on this account and for the comparatively forward position of the eyes (itself a nepionic character), together with the large number of thoracic segments, it stands near the base of the series.

The eyes gradually approach the axis, and move backward through the genera *Tropidocoryphe*, *Cyphaspis*, *Proëtus*, *Prionopeltis*, *Phillipsia*, and *Griffithides*. Concurrent with this variation, there is a reduction of the fixed cheeks and extension of the glabella. In *Arethusina*, *Tropidocoryphe*, *Cordania*, and *Cyphaspis*, the fixed cheeks are about the size of the free cheeks, and occupy a large portion of the cranidium. They are more reduced in *Proëtus* and *Prionopeltis*, and in *Phillipsia* and *Griffithides*, they form only a narrow border to the glabella. The lobation of the glabella varies greatly, and few species retain evidences of its original segmental nature. Some *Proëtus* and *Dechenella* show this feature, but in many *Phillipsia* and *Griffithides* the elements cannot be made out. In *Proëtus*, there is often a small accessory lobe developed at the ends of the neck ring, which is only of interest as being homologous with similar lobes in many of the Lichadidæ and Acidaspidæ, where they often become very conspicuous. In all the Proëtidæ, the oblique lobes of the fourth annulus of the glabella are also important in this connection, as here again is marked the inception of side axial lobes, which become prominent features in higher genera, indicating greater specialization of the organs and appendages of the head.

Family VIII. Bronteidæ Barrande.

Dorsal shield broadly elliptical. Cephalon less than one-third the entire length; glabella rapidly expanding in front, with faint indications of lobes. Free cheeks larger than the fixed cheeks. Facial sutures extending from the posterior margin just behind the eyes abruptly inward around the palpebral

lobes, and then diverging and cutting the antero-lateral margins separately. Eyes crescentic. Thorax of ten segments, with ridged pleura. Pygidium longer than cephalon or thorax; axis very short, with radiating furrows extending from it across the broad limb toward the margin; doublure very wide; margin generally entire. Ordovician to Devonian.

Including the single genus *Bronteus* Goldfuss (= *Goldius* de Koninck).

Many of the species of *Bronteus* (as *B. angusticeps* Barr., *B. palifer* Bey.) show a breaking up of the glabella into symmetrically disposed separate lobes, as in *Conolichas* and *Acidaspis*. The frontal lobe is transverse and much larger than the others. Back of it may be simple grooves marking the elements (*B. campanifer* Bey.), or there may be one or two circular or elliptical swellings on each side of the axis (*B. angusticeps* Barr.), or in addition, the axial portion may consist of several lobes. The reduction of the axis of the pygidium and the expansion of the limb meet with their greatest expression in this genus. *Lichas* shows the decline of these characters, the pygidial limb becoming more or less deeply lobed, and finally the lobes are represented by spines (*Arges*, *Terataspis*). Further progression of these changes is shown in *Acidaspis*.

Family IX. Lichadidæ Barrande.

Dorsal shield generally large and flat, with granulated test. Cephalon small, not more than one-fourth the entire length; genal angles spiniform. Free cheeks separate; sutures extending from the posterior margin obliquely inward to the eyes, and then almost directly forward, cutting the margin separately. Glabella broad, with a large, often tumid, central lobe and from one to three side lobes. Eyes not large. Thorax with nine or ten segments and grooved and falcate pleura. Pygidium large, flat, commonly with toothed or notched margin corresponding to the pleural grooves; doublure very broad.

Ordovician to Devonian.

Including the genera and subgenera *Lichas* Dalman, *Arctinurus* Castelnau, *Arges* Goldfuss, *Ceratolichas* Hall and Clarke, *Conolichas* Dames, *Dicranogmus* Corda, *Homolichas* Schmidt, *Hoplolichas* Dames, *Leiolichas* Schmidt, *Metopias* Eichwald, *Oncholichas* Schmidt, *Platymetopus* Angelin, *Terataspis* Hall, *Trochurus* Beyrich, and *Uralichas* Delgado.

Most of the forms of this family are above the average size of trilobites, and several species are among the largest of the class. They are all thin-shelled, and were loosely articulated, so that entire specimens are extremely rare.

A great diversity is shown in the form and lobation of the glabella. In *Lichas* (sens. str.), *Platymetopus*, and *Leiolichas*, the anterior lobe dominates and is continuous with the axis. In *Hoplolichas* and *Homolichas*, the lateral lobes are strongly defined, and each is nearly equal in size to the central lobe. *Dicranogmus*, *Oncholichas*, *Conolichas*, *Metopias*, *Arctinurus*, and *Arges* show the lateral lobes divided transversely into two or three smaller ones. Lastly in *Ceratolichas*, and more especially in *Terataspis*, the central lobe becomes a prominent ovoid or globular extension. These variations evidently indicate differences in the relative development of the appendages and organs of the head, and therefore are of considerable morphological importance.

The pygidium is composed of few distinct segments. The annulated portion of the axis is generally short, and the dentations on the border of the limb, corresponding to the pleural grooves, range from two to four on each side. *Leiolichas* is the only form which has an entire pygidial margin.

Family X. Acidaspidæ Barrande.

Dorsal shield spinose. Cephalon transversely semi-elliptical, quadrate, or trapezoidal; genal angles spiniform. Glabella with one large median axial lobe and two or three lateral lobes. Free cheeks large, separate. Sutures extending from within the genal angles abruptly inward to the eyes, and then forward, cutting the anterior margin each side of the glabella. Eyes small, often prominent. Thorax of eight to ten segments, with ridged pleura extended into hollow spines. Pygidium usually small, with spinous margin. Ordovician to Devonian.

Including the genera and subgenera *Acidaspis* Murchison, *Ancyropyge* Clarke, *Ceratocephala* Warder, *Dicranurus* Conrad, *Odontopleura* Emmrich, and *Selenopeltis* Corda.

In this family and the Lichadidæ is shown the highest expression of differentiation and specialization of the Opisthoparia. The primitive pentamerous lobation of the axis of the cranidium is entirely obscured, and is only clearly seen in the protaspis and early nepionic stages. These two families are very closely related, the chief differences being noticed in the size and character of the pygidium, and the ribbed or grooved

pleura. The Lichades are generally much larger and flatter, but the smaller and highly spinose forms of *Arges*, *Ceratolichas*, and *Hoplolichas* approach quite near some of the Acidaspidæ.

It has been customary of late years to regard all the species of this family as belonging to the single genus *Acidaspis*, and to consider the various subdivisions bearing separate names as of the value of subgenera. Clarke" has shown that, on the basis of priority, *Ceratocephala* is the first distinctive name ever applied to the group, and is therefore entitled to full generic recognition. He further recognizes *Odontopleura*, *Acidaspis*, *Dicranurus*, *Selenopeltis*, and *Ancyropyge*, in the subordinate position of subgenera under *Ceratocephala*.

Order C. PROPARIA, n. ord.

(πρό before, and πᾶρειά cheek piece.)

Free cheeks not bearing the genal angles. Facial sutures extending from the lateral margins of the cephalon in front of the genal angles, inward and forward, cutting the anterior margin separately or uniting in front of the glabella. Compound paired eyes scarcely developed or sometimes absent in the most primitive family, well-developed and schizochroal in last family.

Including the families Encrinuridæ, Calymenidæ, Cheiruridæ, and Phacopidæ.

Salter's first division, *Phacopini*, included the two families Phacopidæ and Cheiruridæ. The Calymenidæ were placed in his second division, the *Asaphini*.

This is the only order of trilobites which apparently begins within the known Paleozoic, and unlike the other orders, it had no pre-Cambrian existence. The earliest forms of the Proparia came at the close of the Cambrian, in the lower Ordovician. Its greatest generic differentiation was attained early. There is a rapid decline in the Silurian and Devonian, and only one or two genera extend to the beginning of the Carboniferous.

In the Opisthoparia, it was demonstrated that the Conocoryphidæ formed the natural base or most primitive family in the order, and was distinguished by the narrow marginal free cheeks and the absence of well-developed eyes. It is of much interest and importance to be able to recognize, in the Proparia, a similar primitive family having characters in common with the former, but still clearly belonging to the higher order. *Placoparia*, *Areia*, and *Dindymene*, of the Encrinuridæ, constitute a group of apparently blind trilobites, with narrow mar-

ginal free cheeks, presenting in general the appearance of *Atops*, *Conocoryphe*, *Ctenocephalus*, etc., of the Conocoryphidæ. The somewhat higher genera *Cybele* and *Encrinurus* have intermediate or transitional characters, leading to the other families. The Cheiruridæ show a greater amount of differentiation and progressive and regressive evolution than any other in this order. *Crotalocephalus* and *Sphærexochus* seem to express the highest development, and *Deiphon* and *Onycopyge* show the effects of over specialization, resulting in degeneration. The Calymenidæ, in their small eyes and narrow free cheeks, have decided affinities with the lower genera. The same may be said of *Trimerocephalus* of the Phacopidæ, though the other genera of this family possess large eyes, situated well back and close to the glabella. For these and other reasons, the family is placed at the end of the order, as expressing its highest development.

Family XI. Encrinuridæ Linnarsson.

Cephalon narrow, transverse. Fixed cheeks very large. Free cheeks long, narrow, separate, sometimes with a free plate between the anterior extremities. Sutures extending from in front of the genal angles obliquely forward, and cutting the anterior margin in front of the glabella. Eyes very small or absent. Thorax of from nine to twelve segments, with ridged pleura. Pygidium generally composed of many segments; limb with strong ribs usually less in number than the annulations of the axis. Ordovician and Silurian.

Including the genera *Encrinurus* Emmrich (*Cromus* Barrande), *Areia* Barrande, *Cybele* Lovén, *Dindymene* Corda, *Placoparia* Corda, and *Prosopiscus* Salter.

The Conocoryphidæ were shown to be the radical of the order Opisthoparia, and for similar reasons, the Encrinuridæ may now be taken as the primitive family of the Proparia. The cephala of *Areia* and *Placoparia* have many resemblances to *Conocoryphe*, but the fixed cheeks bear the genal angles and spines, while in the latter genus they are on the free cheeks. In both families, the free cheeks are narrow and marginal, and the eyes are absent or rudimentary. Both these characters are decidedly larval. Other primitive and larval features belonging to the Encrinuridæ are the eye lines in *Cybele* and *Encrinurus*, the undefined and expanded termination of the glabella in *Dindymene* and *Encrinurus*, and the pentamerous head axis in all but *Dindymene*, in which the four anterior lobes or

annulations are obsolete. In *Encrinurus*, the eye line in meeting and joining the anterior lobe of the glabella sometimes gives the appearance of an extra lobe, as in *Ogygia* and *Paradoxides*.

Family XII. Calymenidæ Brongniart.

Cephalon somewhat wider than long. Fixed cheeks large; genal angles rounded or produced into spines. Glabella narrowing anteriorly. Free cheeks long, separate, usually with a free plate, the epistoma, between the anterior extremities. Sutures extending from just in front of the genal angles, converging anteriorly, and cutting the margins separately. Eyes small; visual surface seldom preserved. Thorax of thirteen segments, with grooved pleura. Pygidium of from six to fourteen segments; axis tapering. Ordovician to Devonian.

Including the genera and subgenera *Calymene* Brongniart, *Brongniartia* Salter, *Burmeisteria* Salter, *Calymenella* Bergeron, *Calymenopsis* Munier-Chalmas and Bergeron, *Dipleura* Green, *Homalonotus* Koenig, *Koenigia* (= *Homalonotus*) Salter, *Pharostoma* Corda, *Plæsiacomia* Corda, *Ptychometopus* Schmidt, and *Trimerus* Green.

The genera of this family naturally cluster around the two leading ones, *Calymene* and *Homalonotus*. Closely related to the first are *Ptychometopus*, *Pharostoma*, *Calymenopsis*, and *Calymenella*, all agreeing in having the glabella well defined and marked by furrows or indentations at the sides, corresponding to its segmental nature.

The second group, including *Brongniartia*, *Trimerus*, *Homalonotus* (sens. str.), *Plæsiacomia*, *Dipleura*, and *Burmeisteria*, agree in having a low, not sharply defined, quadrate glabella, without distinct furrows or lobes. In general, the axis of the thorax and pygidium is much wider than in the first group, and the pygidium is more elongate and often pointed.

Family XIII. Cheiruridæ Salter.

Glabella well defined. Free cheeks small, sometimes much reduced. Sutures extending from in front of the genal angles inward to the eyes, and then obliquely forward, cutting the anterior margin in front and each side of the glabella. Eyes usually small. Thorax composed of from nine to eighteen segments, generally eleven; pleura often extended into hollow spines. Pygidium small, with from three to five segments; pleural elements commonly produced into spines.

Principally Ordovician and Silurian, but extending into the Devonian.

Including the genera and subgenera *Cheirurus* Beyrich, *Actinopeltis* Corda, *Amphion* Pander, *Anacheirurus* Reed, *Ceraurus* Green, *Crotalocephalus* Salter, *Cyrtometopus* Angelin, *Deiphon* Barrande, *Diaphanometopus* Schmidt, *Eccoptocheile* Corda, *Hemisphærocoryphe* Reed, *Nieszkowskia* Schmidt, *Onycopyge* Woodward, *Pseudosphærexochus* Schmidt, *Sphærexochus* Beyrich, *Sphærocoryphe* Angelin, *Staurocephalus* Barrande, and *Youngia* Lindström.

As in other families, the most primitive genera are those in which the regular pentamerous lobation of the glabella is retained, the eyes are well forward, the free cheeks narrow, and the fixed cheeks ample. *Diaphanometopus*, *Anacheirurus*, *Eccoptocheile*, and *Cyrtometopus* agree in these respects, and therefore belong at the beginning of a phylogenetic list. *Ceraurus* and *Nieszkowskia* appear to branch off here, being characterized by the narrow transverse form of the cephalon and the great development of the two anterior pygidial pleura into hollow spines directed outward and backward. These features are simulated in *Deiphon*, in which, however, the prominent glabella is without distinct lobes, and the large pleural extensions of the pygidium do not belong to the anterior segment. Its natural place is at the end of the series. F. Cowper Reed[31] has shown, in his memoir on the evolution of *Cheirurus* and its subgenera, not including the other genera of the family, that the direct line from *Cyrtometopus* passes through *Cheirurus* to *Crotalocephalus*. The genera *Pseudosphærexochus* and *Amphion* also have relations with these genera and should be placed here. There is next a group of forms, with prominent globular glabellæ, leading from *Cheirurus* to *Sphærocoryphe*, and including *Actinopeltis*, *Youngia*, and *Hemisphærocoryphe*. *Staurocephalus* should immediately follow these. *Sphærexochus* seems to be related to *Cheirurus* and *Actinopeltis*. Like them, it has two side lobes at the base of the glabella, and the anterior furrows are obsolescent, as in *Actinopeltis* and *Youngia*. Lastly come *Onycopyge* and *Deiphon*, with their globular glabellæ without furrows, the spiniform fixed cheeks, and thoracic and pygydial pleura, and the free cheeks reduced to almost nothing, forming a small part of the doublure of the cephalon. The former genus has four spiniform pygidial pleura, two on each side, but in the latter, two are reduced and the remaining pair is greatly enlarged.

Family XIV. PHACOPIDÆ Salter.

Glabella tumid, widest in front. Free cheeks continuous, united anteriorly. Suture extending from in front of the genal angles inward to the eyes, and then forward around the glabella. Eyes generally large, and always with distinct facets, schizochroal. Thorax with eleven segments, with grooved pleura. Pygidium usually large and of many segments; limb ribbed; margin entire or dentate. Ordovician to Devonian.

Including the genera and subgenera *Phacops* Emmrich, *Acaste* Goldfuss, *Chasmops* McCoy, *Coronura* Hall, *Corycephalus* Hall and Clarke, *Cryphæus* Green, *Dalmanites* Emmrich (*Hausmannia* Hall and Clarke), *Homalops* Remele and Dames, *Monorachos* Schmidt, *Odontocephalus* Conrad, *Pterygometopus* Schmidt, *Symphoria* Clarke, and *Trimerocephalus* McCoy.

The last family of trilobites comprises forms which are commonly believed to be the most highly organized of the class, and certain it is that a high degree of organization is manifested. Some of the characters may be considered as progressive, while others are larval or possessed chiefly by the most primitive families, and are therefore to be looked upon as regressive. Schizochroal eyes occur in no other family, and this feature is apparently indeterminate. The complete union of the free cheeks, carrying the doublure of the sides and front of the cephalon, can be best homologized with similar structures in some of the lowest genera, and is a retention of the complete occular segment. The glabella, though considerably enlarged anteriorly, does not attain the degree of specialization shown in *Lichas* and *Acidaspis*. Only *Chasmops* and related forms (*Monorachos*, *Homalops*, *Symphoria*, and *Coronura*) have separate or accessory lobes. The margin of the cephalon shows even greater diversity than in any other family. It may be plain (*Phacops*, *Cryphæus*), notched (*Corycephalus*), denticulated (*Odontocephalus*), or extended in front as a spinose, spatulate, or dentate process (*Dalmanites nasutus* Conrad, *D. tridens* Hall, etc.). The pygidium has a range almost as great, though in this respect it is equalled in the Lichadidæ, Acidaspidæ, and some of the Olenidæ. In America, the section typified by *Dalmanites* culminated during the lower Devonian. Not only are the largest forms found here (*Coronura diurus* Green, *C. myrmecophorus* Green, *D. tridens* Hall, etc.), but also the most ornate and specialized, as *Corycephalus*, *Odontocephalus*, and *Coronura*.

Yale Museum, New Haven, Conn., December 28th, 1896.

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EXPLANATION OF PLATE III.

Figures are approximately of the same size to facilitate comparison. The dorsal areas of the free cheeks are shaded.

Ontogeny of Sao hirsuta Barrande.

FIGURE 1.—Protaspis stage.
FIGURE 2.—Cephalon; nepionic stage of individual having two free thoracic segments.
FIGURE 3.—Cephalon; later nepionic stage of individual having eight free thoracic segments.
FIGURE 4.—Cephalon of adult. Figures 1–4, after Barrande.

Ontogeny of Dalmanites socialis Barrande.

FIGURE 5.—Protaspis stage.
FIGURE 6.—Cephalon; nepionic stage of individual having three free thoracic segments.
FIGURE 7.—Cephalon; nepionic stage of individual having seven free thoracic segments.
FIGURE 8.—Cephalon of adult. Figures 5–8, after Barrande.

HYPOPARIA.

FIGURE 9.—Cephalon of *Agnostus.* } Agnostidæ.
FIGURE 10.—Cephalon of *Microdiscus.* }
FIGURE 11.—Cephalon of *Harpes.* } Harpedidæ.
FIGURE 12.—Cephalon of *Trinucleus.* } Trinucleidæ.
FIGURE 13.—Cephalon of *Ampyx.* }

OPISTHOPARIA.

FIGURE 14.—Cephalon of *Atops.* } Conocoryphidæ.
FIGURE 15.—Cephalon of *Conocoryphe.* }
FIGURE 16.—Cephalon of *Ptychoparia.* } Olenidæ.
FIGURE 17.—Cephalon of *Olenus.* }
FIGURE 18.—Cephalon of *Asaphus.* } Asaphidæ.
FIGURE 19.—Cephalon of *Illænus.* }
FIGURE 20.—Cephalon of *Proëtus.* } Proëtidæ.
FIGURE 21.—Cephalon of *Bronteus.* } Bronteidæ.
FIGURE 22.—Cephalon of *Lichas.* } Lichadidæ.
FIGURE 23.—Cephalon of *Acidaspis.* } Acidaspidæ.

PROPARIA.

FIGURE 24.—Cephalon of *Placoparia.* } Encrinuridæ.
FIGURE 25.—Cephalon of *Encrinurus.* }
FIGURE 26.—Cephalon of *Calymene.* } Calymenidæ.
FIGURE 27.—Cephalon of *Dipleura.* }
FIGURE 28.—Cephalon of *Cheirurus* (*Eccoptocheile*). } Cheiruridæ.
FIGURE 29.—Cephalon of *Dalmanites.* }
FIGURE 30.—Cephalon of *Dalmanites.* }
FIGURE 31.—Cephalon of *Chasmops.* } Phacopidæ.
FIGURE 32.—Cephalon of *Acaste.* }
FIGURE 33.—Cephalon of *Phacops.* }

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ERRATA.

Page 92, line 19, for *Zecanthoides* read *Zacanthoides*.
Page 95, line 24, for enervate read innervate.
Page 95, line 25, for enervated read innervated.
Page 96, lines 31 and 34, for enervating read innervating.
Page 103, line 18, for *Olenellus* read *Elliptocephala*.

Art. XIX.—*The Scoured Bowlders of the Mattawa Valley;* by F. B. Taylor.

Introduction.

The author spent the last week in September and the first half of October just passed in exploring the valley of the Mattawa river in the Province of Ontario. The chief object of search was to discover whether there is any clear evidence of the recent flow of a great river eastward along this course to the Ottawa valley. For this is the site of a supposed former outlet of the upper Great Lakes. It has been supposed, first by Mr. G. K. Gilbert, and later by Prof. G. F. Wright and the author, that there was a period since the disappearance of the ice-sheet during which Lakes Superior, Michigan, and Huron discharged their waters eastward to the Ottawa valley along the present course of the Mattawa river. During this period Lake Erie alone retained its outlet through Niagara river to the basin of Lake Ontario. It does not fall within the intended scope of this paper to discuss all the facts relating to the existence of the Nipissing-Mattawa river, as the ancient outlet river may be called, nor to discuss exhaustively the facts relating to its duration and date. It will suffice here to state that from several kinds of evidence the existence of the great outlet river is believed to be established beyond a doubt; and further, that it endured for a comparatively long period of time and ceased to exist probably considerably less than ten thousand years ago. Hence, while it is geologically a very recent thing, it may very properly be spoken of in a historical sense as ancient.

No more conclusive evidence of the existence of the ancient river could be expected than that which has been gathered this season from a study of the numerous bowlders that lay in its rapids. The volume of the river, it is fair to assume, was practically the same as that of the St. Clair river to-day, and was equally steady in its flow. In rapids of moderate velocity, where the river flowed over a sill closely paved with large bowlders, the action of the current rolling small quantities of gravel over, around and between the bowlders produced certain wearing or scouring effects which are very characteristic. The forms so produced are not known to be made in any other way. It is the object of this paper to present a brief account of these peculiar bowlders as they appear to-day in the valley of the Mattawa, many of them as much as forty feet above the present river. A few remarks will also be added about the conditions and the processes of their production.

The bowlders which show these modifications are almost all large, ranging from about two to twenty-five or thirty feet in diameter. Bowlders of large size are extremely numerous on the areas where these forms are found, completely covering over the surface of the ground. They are all of very hard crystalline rock; some are red or gray granite, and some are greenstones, but by far the greater number are of the hard foliated gneiss which is so common in the surrounding region. Many of the large bowlders of gneiss, even after the long exposure to weather which they have undergone, show no signs of fracture or breaking. So far as observed the bowldery areas of the former rapids of the river appear to be associated with belts of morainic accumulation.

Varieties.

One may best learn the processes by which scoured bowlders are made by studying the action of the current in bowldery rapids of the modern river at a time of low water. In passing over and among the bowlders the current is very much disturbed. It is turned aside suddenly and thrown this way and that; it strikes against the front or the sides of some bowlders and passes through narrow passages between others; it glides smoothly over the tops of some and falls heavily on the tops of others, and in a few cases it is thrown into a vortex whirl in an angle or slight depression on the surface of a bowlder. Just as the billows in a rocky rapid remain constant in position, so these various turns and whirls in the current beneath the surface remain constant in place and action so long as the bowlders lie unmoved. Thus the currents that play upon a bowlder are generally constant in the particular manner of their action. Where sand and small pebbles are being borne along in small or moderate quantities, they follow the deviations of the current from bowlder to bowlder, and each sand-grain and pebble does a little work of abrasion as it goes along. Every one that follows the same course among the bowlders performs its iota of work upon the same part, so that the wear on each bowlder comes where the current impinges upon it. In the course of time, but very slowly, the bowlders are worn into the fantastic shapes which are here called scoured bowlders. The forms which the bowlders take under the scour of the sand- and pebble-bearing current are quite varied. But after examining several hundreds of specimens it became apparent that all could be classified according to their forms under a few heads, although a few individual cases would have to stand as intermediate forms. Six varieties may be distinguished as follows:

Scoured Bowlders.

1. Pierced (Ring-bowlders).
2. Basined.
3. Niched.
4. Guttered.
5. Facetted.
6. Smoothed.

The table of varieties of form as given above is offered only provisionally. For it is quite probable that a more extended study of the subject would suggest some modifications. In forming the table, however, the writer has had the advantage of discussion and joint observation with Dr. Robert Bell, Assistant Director of the Geological Survey of Canada. Shortly after the beginning of the study of the bowlders at Mattawa, Dr. Bell arrived from James Bay and during three or four days delay from other causes, gave a part of his time to the study of the scoured bowlders. The names of some of the varieties as presented in the table were suggested by him. These names are based mainly on forms of scoured bowlders found on the terraces at Mattawa and in the modern rapids of the Mattawa and Ottawa rivers. The observations of this season, however, are not the only ones that the writer has made. Basined bowlders were observed in 1895 in the rapids of the Ottawa both above and below Mattawa and also in the rapids of the Nipigon. Some of the less pronounced forms were found in 1894 in several of the streams that course down the slopes of the Alps, in the Maggia especially, and to some extent also in the Toce and Ticino. In 1893 a few basined bowlders were seen in the Au Sable and Saranac rivers in the Adirondacks. The first bowlders of this kind noted by the writer were seen in 1888 and 1889 in some of the rapids of Grand river above Hot Sulphur Springs in Middle Park, Colorado, and they were also seen in several other rivers in the same state. Some of those in Grand river show well-developed potholes.

Distribution.

Scoured bowlders of the more pronounced types may be produced in almost any stream of large or moderate size provided certain conditions of stability obtain. The bowlders must be permanent in position for a long period, and the general direction of the current must not change. There must also be a fairly constant supply of sand and gravel, moderate in amount, for the current to roll along as it moves over the bowlders. Streams meandering in alluvial plains are not likely to show effects of this kind. Even streams flowing in drift beds suffer so many alterations of their courses, due to caving banks and

deepening beds, that they produce generally only the smoothed variety, which does not require constancy of position. Nearly all streams produce this simplest form. Scour effects on bowlders are sometimes found even in small streams, where their courses are permanently choked with great bowlders through which the stream trickles constantly. But so far as known to the writer, the Mattawa valley is the first case where the existence of a great ancient river now extinct has been inferred from such evidence.

Besides the scoured bowlders on the terrace at Mattawa there is but one other place higher up the Mattawa valley where these peculiar stones were made in large numbers in rapids of the ancient river. At Des Epines rapids, eight and one-quarter miles above Mattawa, scoured bowlders are developed in great profusion and perfection of form at heights entirely above the reach of the modern river. At this place bowlders with deep basins or potholes in them were found on the north side over forty feet above the water.

On a comparison of the results of observations on the several bowldery rapids of the ancient river, a very clear explanation of the plentiful occurrence of scoured bowlders in some rapids and their scarcity or absence in others was found. Wherever a stream of sufficient volume to transport gravel in considerable quantities descended from the adjacent high drift-covered country and poured its contribution into the ancient outlet at or just above a rapid, scoured bowlders are numerous. But where the water that passed over the bowlders issued directly from a lake, and hence without any such supply of gravel, scoured bowlders are few or absent altogether. Boom creek entered the ancient outlet on the south side about a mile above Mattawa and furnished an abundant supply of gravel for the current to roll along over the bowlders of the Mattawa terrace. That Boom creek did in fact supply a large amount of gravel is attested by the present existence of a very considerable delta of sand and gravel 50 to 60 feet above the modern Mattawa river where the creek enters the old channel. The influence of the ancient outlet current is shown by the fact that these sediments have been carried down that side of the channel quite extensively and spread over part of the bowldery terrace. At Des Epines rapids the gravel supply came from the Amable du Fond river, which enters on the south side less than half a mile above. This stream is nearly as large as the Mattawa itself and it cuts extensive gravel beds a short distance above its mouth.

On the other hand, in the bowldery rapids at the head of Lost river (foot of Turtle lake) no basined bowlders and few even of the less pronounced forms of scour were found. They

appeared to be absent also in the ancient bowldery rapids next below Pimisi bay and at the Rapide des Rochers below Lac des Aiguilles. At all these places the current issued directly from a lake and was probably clear and free of gravelly sediments.

So far as seen the best place to observe bowlders being scoured by the work of the modern Mattawa river is at the Chute des Parasseux, fourteen miles above Mattawa.

Descriptive Details of Varieties.

Pierced and basined bowlders are in reality merely two stages of the same process. When the current begins to cause pebbles and sand to spin round and round on one particular spot on the surface of a bowlder, the process of wearing out a basin is begun. Given only time enough, with constancy of the conditions on which the whirl depends, and the basin will sink deeper and deeper into the solid bowlder until the bottom is cut through and the basin becomes a hole. The bowlder is then pierced through and becomes a ring-bowlder. The hole is usually nearly circular on cross section, but sometimes tapers towards the bottom. The periphery or outer surface of the stone generally shows considerable irregularity, for the hole is seldom symmetrically placed. Otherwise these bowlders have the common sub-angular form. Pierced or ring-bowlders are the highest type or variety of the several forms produced by scour. They are scarce, even where other lower varieties are abundant. Only one was found on the course of the ancient outlet river within the Mattawa valley, and this lies in such a position and at so low a level with reference to the modern river that it probably was made by it. This ring-bowlder lies in a side channel at Parasseux Chute. A dam was constructed across the head of the rapids several years ago and this left a side channel east of the present rapids dry. In the bottom of this channel about opposite the middle of the present rapids below the dam lies the ring-bowlder. It is broken in two pieces, but they are separated only a few inches and their former solidity as an unbroken ring is at once obvious. The hole is not perfectly circular, but has a large diameter compared with the diameter of the bowlder itself. The hole is about eighteen inches across, while for about one-third of the circumference the ring of rock is only six or seven inches thick.

But the most magnificent specimen of this variety that the writer has seen is on the bank of the Ottawa river near Klock's, ten miles below Mattawa. This bowlder is large—about seven feet long, five wide and four thick. The hole is

about eighteen or twenty inches across at the top, but tapers to about eight or ten inches at the bottom. The bowlder has evidently been slightly tilted since it was bored out, and may, indeed, have been moved a considerable distance. It lies at the edge of the water a few rods up stream from the residence of the Hon. James B. Klock, and is readily visible only at low water.

From the Rev. E. Macnab of Mattawa the writer learned of another ring-bowlder which may be seen on the bank of Lake Temiscamang at the narrows at old Fort Temiscamang near Baie des Pères. In this case a tree grew up through the aperture and finally broke the bowlder in two. The stone was literally strung on the tree.

Basined bowlders are much more numerous. They are fairly abundant in the rapids of the ancient outlet at Des Epines rapids and at Mattawa and also in several of those of the modern Mattawa and Ottawa. They exist in all stages of development ranging from a saucer-like depression barely deep enough to hold a spoonful of water to well-developed potholes a foot or more in depth. Occasionally one is found which is very irregular in shape —a peculiarity which is generally due to some unevenness in the composition of the rock. Several bowlders were found in which a well-developed basin had a deep cut in the rim or on one side. This appeared to be due to the wearing through of a thin side wall. A good specimen of this modified form lies on the edge of the railroad cut about forty feet south of the overhead bridge opposite O'Farrell's hotel in Mattawa. This one is about 35 or 40 feet above low water in the Mattawa. Many basined bowlders were found at heights from fifteen or twenty up to about forty feet on ground east and southeast of the hotel. On the north bank at Des Epines rapids three good specimens were found forty feet above the modern Mattawa and several others were found at lower levels.

Niched bowlders that can be surely distinguished from other forms are hardly so common as the basined variety. The niche is a shallow hollow worn into the side of the bowlder, in form somewhat resembling a wall-niche for statues or statuettes. A number of examples were found at Mattawa concerning which there can be no doubt. For the bowlder had evidently received its marks of scour *in situ*. This was the case with the great bowlders especially. In the case of many small bowlders, however, the worn cavities may have had a different origin. If a small bowlder had a small shallow basin worn on its top and then had been turned over on its side, the basin would then have the appearance of a true niche. No doubt many have had this origin. But in several instances it was plain that the niche had been worn while the bowlder was in exactly the same position as to-day.

Shallow, smooth-worn hollows are often found on the slanting sides of bowlders, and sometimes on stones no larger than a foot in diameter. The origin of such forms can seldom be made out with certainty unless it is clear that the stone has remained unmoved. In a few cases two bowlders lying close together had complementary grooves or hollows in them. Probably nearly all true niches were caused by the diversion of the current by one bowlder so as to strike the side of another.

Guttered bowlders in typical form are almost as rare as ring-bowlders. It requires a bowlder having considerable flat or nearly flat surface area on its top to lead to the formation of a gutter. Hence this variety is confined mainly to bowlders of large size. The flat surface must have some slight inequalities that will tend to guide the sand and pebbles which the current rolls along. If these irregular features are so arranged that the wearing materials are always guided along the same path they will finally wear it smooth and deepen it more or less, making a sort of gutter across the surface of the bowlder. Such smooth-worn grooves are often found where streams flow over solid rock ledges. But they are not so common on bowlders. Where they exist under such circumstances that the bowlder has clearly not been moved, they show the direction of the current very accurately. There is one fairly good example of this variety in Mattawa, and also several others less noteworthy. But even this best one is not so strongly marked nor so perfect as could be wished. Still, it has the distinct characters of a gutter, and was produced by the process just described. Twenty-five or thirty rods north of the bridge on the east side of the Mattawa river at its mouth are several very large bowlders. One is of gigantic size, having dimensions of about 27 feet in length, 24 feet in width and fully 15 feet in height, with probably a third of its bulk buried under ground. It is about 150 feet back from the river and the ground at its base is about ten feet above the water. It is a block of foliated gneiss and shows considerable differential weathering or wearing on its sides where the black hornblendic bands project as ribs nearly horizontal, while the gray quartz-feldspar bands between are relatively depressed by being worn or dissolved out. The top of this great bowlder is somewhat uneven, but it slopes in a general way toward the south-southwest or up-stream with reference to the Mattawa. The uneven features of the top surface present their sharper edges and bolder faces toward the northeast. A fairly well developed gutter runs across diagonally from corner to corner in a straight line. Starting at the southwestern corner, it runs up a slope of about 20° to the northeast. Near the lower edge the surface is comparatively plane, having few irregularities and the gutter is scarcely noticeable. But within a foot or two a slight depression appears between very gently sloping sides, and the sand and

pebbles seem to have been gathered into this and so started on their course. This depression was plainly an original feature of the surface of the bowlder. But on close inspection it was found that the bottom had been made a little more even and smooth by the sand that had trailed along through it. Then for two or three feet the surface is flat and the sand and pebble current appears to have spread out or divided in two or three parts. Over this space the gutter is not clearly discernible. Then another depression begins and runs three or four feet to the sharp edge of a cavity about one foot in depth. On approaching the edge the gutter becomes very marked, and the edge where the moving materials ran over into the cavity is worn and hollowed out smooth into a shape like the lip of a large water pitcher. After passing out of the cavity and up the face of the bowlder again, the worn track reappears directly in line with that just described and becomes more pronounced as it approaches another worn-down notch or pitcher-lip where the gutter passes off the bowlder into the air. This worn track crosses the whole extent of the bowlder in a direct course, and from its relation to the worn notches in the sharp edges it is plain that the course of the sand and pebbles was from southwest to northeast and not *vice versa*. In sighting backward along the gutter, one looks directly up the course of the Mattawa. At the same time the bowlder stands in such a position that it would be openly exposed to higher waters from the northwest descending the valley of the Ottawa. But there are no marks indicating the action of a current from that direction. The top of the bowlder at the present time is about 25 feet above the water at low stage.

In another way the giant bowlder shows conclusively that a great current of water has played around it. It stands in a sort of basin and rests its lower visible edges against smaller bowlders from between which all finer material has been swept away. Open holes now filled with water extend some distance down under the edges of the great bowlder. The other bowlders now immediately surrounding the great one are mostly small. It seems probable that the great bowlder was at first buried more deeply than now. The gutter may, therefore, have been made mostly in the earlier stages of the great river, when sand and gravel would pass more readily over its top. The basin it lies in suggests this, and it is hard to see how sand or gravel could be carried up onto the top of the bowlder, as it stands related to the surrounding ground to-day, in sufficient quantities to accomplish such a work.

There is another cluster of very large bowlders near the railroad trestle northeast of the great bowlder mentioned above. Some of them show faint gutters also and nearly all of them show basins or some other well-marked product of scour. Among smaller bowlders the gutter is frequently rep-

resented by notches in the rims of shallow basins. These are well marked sometimes, showing where the sand and pebbles left the basin, and occasionally a notch is found also on the up-stream side where they entered, if the bowlder be not too small and its up-stream rim too narrow.

Facetted bowlders have plane faces or facets worn smooth. Probably in nearly all cases the facets existed in the rough before the scouring. It would be hard in any given case to prove that this was not true. Still, it is possible that facets have sometimes been made by scour when the facet shape did not previously exist. This variety is fairly plentiful.

Smoothed bowlders are far more abundant than all the other varieties put together. Almost every bowlder that has a more specific mark of scour shows smoothed surfaces also on other parts. A smoothed bowlder is one that has simply been made smooth by scouring and may not have received any other more definite mark in the process. These bowlders may have been angular or subangular or rounded before the scouring began, and without having their general form changed they were made smooth over all surfaces alike. In the old channels where the scoured bowlders occur almost every one shows more or less of this effect. There are great numbers of scoured bowlders along the roadside near the Presbyterian church in Mattawa and farther east for a quarter of a mile. Near the church there are many fine examples of smoothed and basined bowlders. Some of them are polished so smooth on one or more sides that they glisten a little in the sunshine even when they are dry. They have a smooth, soft feel under the hand, not like a pane of glass, but rather like a surface of finely embossed leather. Most of the bowlders along the road near the church have been moved in road improvement or in clearing ground for buildings. It is probable that the most highly polished parts of the best specimens were previously on the under side or buried, and so protected from the weather ever since they were polished. This suggests that many, at least of the smaller bowlders, were turned over and partly buried during the time of the great outlet river. They were scoured and polished and turned over before the river ceased to flow. It is quite possible that other forms of scour may be found on bowlders which would suggest the propriety of adding more varieties to the list given above. But the forms found by the author, and examined also by Dr. Bell, seem to be fairly well covered by the names suggested.

One other possible variety deserves mention. When the deep cut was made through the bowldery terrace in Mattawa for the branch railroad up the Ottawa, some very curiously shaped stones were found in the gravelly top layer. Among others was one roughly cone-shaped, but flaring out slightly at the base. It is almost perfectly round on any horizontal sec-

tion and tapers smoothly up to a point about two inches through. Its shape may perhaps be best described by saying that it is like an Irish peasant's hat. The crown is rather pointed and the rim projects downward and outward from it through a very gentle curve. The base or bottom of this stone is flat and smooth and showed no rough surface where it might have been detached from the solid mass. From similar specimens seen before, the writer at once recognized this stone as the detached core of a pothole. It is about ten inches high and rather narrow and slender, and hence suggests a pothole of relatively great depth. But the edges around the base or rim are also apparently worn smooth. This makes it very difficult to account fully for its origin. It seems probable that this stone was bored out of a solid bowlder. In that case it is the core left from the making of a ring-bowlder. The bowlder itself might have been smooth on its bottom before the making of the pothole began, and this would go some way toward explaining the smooth bottom of the core-stone. Such stones as this might be set down as an independent variety of scoured bowlders. But so little was learned of the occurrence of this specimen that its place and manner of origin seems to be a matter of some doubt. Nevertheless its smooth and apparently fresh-polished surface suggests that it is a scour product of the rapids of the recent great outlet river. As Dr. Bell has suggested, the ring bowlder out of which this "stone hat" or core-stone was bored may be lying close by hidden in the gravelly, bowldery surface layer (three to seven or eight feet deep), which covers that part of the terrace. Mr. Macnab pointed out another curiously hat-shaped stone on a veranda in the village. It had the shape of a "son'wester," but was clearly the product of differential weathering (perhaps afterwards smoothed in the rapids) rather than of scouring by current action. Dr. Bell deposited the first mentioned specimen in the museum at Ottawa.

Summary.

Some idea of the magnitude of the great outlet river may be gathered from the fact that at Des Epines rapids the mark of its upper limit is quite plain at 50 to 55 feet above the present stream, and the width of the channel at that height is between 600 and 700 feet. The average depth across the channel is 35 to 40 feet, and yet the current was swift enough to produce many of the finest types of scoured bowlders. Here and in Mattawa there are other bowlder fields as heavily covered as those on which the scoured bowlders are found. But they are above the level of the ancient outlet river, and although they were examined closely no scoured bowlders were found upon them. There are also other bowldery tracts at low levels at several places above Mattawa. But they are situated

on the shores of lakes or expanded portions of the valley. Some of these too were explored, but were found devoid of scoured bowlders. It was only in the rapids of the ancient outlet, where a swift and powerful current flowed over them, and where there was a supply of gravel for the current to roll along that the higher types of scoured bowlders were made.

The principal conclusions suggested by the scoured bowlders may be summed up briefly as follows, and in these Dr. Bell is in substantial agreement with the author.

1. The modified bowlders which show the more pronounced forms of scour must have remained a relatively long time in one position and in a current which was substantially constant in strength and direction of flow in order to have received their deep worn and peculiar markings. This conclusion is further supported by the fact that all the bowlders are of hard crystalline rock—mostly of the hardest gneiss and granite.

2. There must have been a constant but not too voluminous supply of gravel or pebbles for the current to roll along over the bowldery bottom in order that the work of scour might be accomplished.

3. Many of the bowlders, especially the larger ones, were scoured *in situ* and in some cases the forms of their scour marks show clearly the direction in which the current flowed.

4. All the indications gathered from the bowlders of the morainic terrace upon which Mattawa is built show that the scouring current came from the Mattawa valley and not from the Ottawa. And this is true, although the best examples relied upon for this conclusion are situated so as to be equally exposed to any current that might have come down the latter valley.

5. The scoured bowlders typified by those at Mattawa and Des Epines rapids constitute a distinct class, which has received secondary modifications of form in consequence of relatively long continued and powerful current action.

6. Beds of scoured bowlders like those here described, marking the place of rapids in great rivers no longer in existence, may serve (with due consideration of other attendant conditions) as valuable aids in the study of later Pleistocene history, especially in the bowldery Archæan areas of the north.

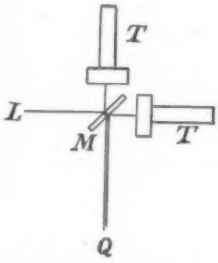
In the opinion of the writer the scoured bowlders are one of the best of several lines of evidence that clearly establish the existence of the great Nipissing-Mattawa river as the outlet of the three upper Great Lakes in very recent times. The conclusion maintained heretofore by Gilbert, Wright and the author, but on evidence less complete, seems now fairly proven, viz: that for a considerable period of time, while this northern outlet was active, Niagara Falls was robbed of much the larger part of its water.

Fort Wayne, Ind., Nov. 28, 1896.

Art. XX.—*Note on the Excursions of the Diaphragm of a Telephone;* by C. Barus.

1. Sometime ago,* while attempting to measure the minimum current audible in a telephone, I encountered a rather remarkable phenomenon: With a continually decreasing current the sound was found to terminate abruptly. A definite interval of silence could be mapped out for gradually increasing currents on either side of zero, and the extent of this interval proved to be 5 to even 15 times the interval of current within which change of sound intensity is appreciable when the limits of the field in question are exceeded. Thus at the margins of the field shades of intensity of about 10^{-7} ampere were acoustically distinguishable, whereas the silent field extended in an average case from -5×10^{-7} to $+5\times10^{-7}$ amperes.

I have since been endeavoring to find some reason for this result, and it occurred to me that the interference apparatus described in my last paper† would be adapted for the purpose. It would merely be necessary to replace the helices shown in the figure there given by two ordinary Bell telephones and to attach a very light mirror to the center of the diaphragm of each, in order to meet the conditions of the experiment. These attached mirrors were but $0{\cdot}05^{g}$ in weight and less than 1^{cm} in diameter. Hence they did not hamper the motion of the diaphragm in any way.



T, T. Telephones.
M, Refractometer plate, Burner beyond
L, Telescope beyond *Q.*

Interference measurements of the excursions of the plate are not new; they were made by Salet‡ and more recently by Francke§ with divergent results (20×10^{-6} to 30×10^{-6} cm in the first case and 10^{-7} cm in the last case). In both instances, however, Newtonian interferences were produced, which for the present purposes are manifestly inferior to the Michelson refractometer.

The subject as a whole has been overhauled in a series of interesting researches due to Prof. C. R. Cross, Cross and Mansfield and others‖ using a stroboscopic micrometer method.

* Barus: Phil. Mag. (5), xxxviii, p. 558, 1894.
† Barus: This Journal, February, 1897.
‡ Salet: Comp. Rend., xcv, p. 178, 1882.
§ Franke: Electrotech. Zeitschrift, xi, pp. 288, 1890.
‖ Cross and Mansfield: Proc. American Acad., xxviii, p. 93, 1892; cf. Experiment with the microphone, ibid., xxv, p. 69, 1890.

They found that if x is excursion or amplitude of vibration in 10^{-4} cm and y the current in milliamperes,

$$y^2 = 0{\cdot}305x^{3{\cdot}26}$$

in very close agreement with their results. They select $y = 2$ as a strong telephone current and thus find the corresponding excursion to be 220×10^{-6} cm, with the remark that the true telephone current is probably somewhat less than this, inasmuch as the field-strength for which the equations hold is somewhat greater than the telephone field.

Now if the current of minimum change of audibility is 10^{-4} milliamperes, as I found, the corresponding change of excursion as called for by the above equation would be 5×10^{-7} cm. Furthermore if the extent of the interval of silence is $\pm 5 \times 10^{-4}$ milliamperes, the smallest excursion obtainable is $1{\cdot}36 \times 10^{-6}$ cm. Hence if all these divers results hang correctly together, the smallest audible excursions of the telephone should be *immeasurable* even with Michelson's refractometer using sodium light. In other words, the sounds should emerge out of the region of silence without producing any disturbance of the interference fringes due to the mirror attached to the telephone diaphragm. This is the case.

2. Putting the telephone in circuit with the secondary of a small induction coil, the primary was supplied with the smallest current sufficient to actuate the interruptor. The telephone was heard to respond quite audibly even when the secondary was left open, for the capacity of the wires was favorable. By closing the secondary circuit with a very large resistance, preferably by putting the fingers in the gap, the sound could be increased to any degree by greater or less pressure of the hand at the contact.

The result with one telephone in circuit showed no change of clearness of the interference fringes when the circuit was left open, although the signal in the telephone (about 50 vibrations per second) was distinct to the ear. I then moved the telescope for observing the fringes to about 6 feet from the telephone and controlled the circuit from this distance. The fringes did not disappear nor indicate motion even when I heard the responding telephone at the telescope or even further away. They became gradually blurred when the circuit was more and more closed with the fingers, but they vanished only for sonorous noises. On the other hand, shouting or loud singing at the distance of the telescope always made the fringes disappear, particularly at certain notes. Thinking that the two telephones (although but one was in circuit) might favor visibility by vibrating sympathetically, I replaced one telephone by a plate mirror without affecting the result.

The induction coil was now removed and replaced with a microphone (dust transmitter with a small transformer) placed over a small music box playing into the mouth-piece of the microphone. All this was removed to a distant room. The tinkling of the music could be heard in the telephone but the fringes remained clear. Finally I placed a small siren under the trumpet of the microphone and produced the usual succession from low to high pitch. As a rule, the fringes were only slightly affected. At certain stages, however, a loud cry was heard in the telephone and the fringes vanished: but these stages seemed clearly to be harmonics. Similarly an organ pipe, f'' ($n = 700$), produced strong resonance and a blank interference field.

It follows, therefore, that if attention be confined to telephonic sounds of faint but distinct audibility, the excursions of the diaphragm must be small as compared with the wave-length of sodium light. Since a single fringe corresponds to 30×10^{-6} cm, and since a shifting or tremor of less than 1/10 fringe is discernible, the excursions of the plate of an ordinary Bell telephone cannot, in the case in question, be greater than 3×10^{-6} cm. They are probably even below 10^{-6} cm.

3. The result with two telephones in circuit was not as I expected to find it, viz: a retention of clearness of the field throughout greater intensities of vibration. If anything, the fringes vanished sooner, and under like conditions were more blurred than for the case of a single telephone in circuit. The reason of this one would naturally seek in a difference in the self inductions of the two telephones, one of which was a more recent Bell telephone and the other an older instrument which had been used by Profs. Blake and Peirce in their early telephone investigations. The plates in diameter, thickness and material were alike, but not the coils. If, however, one inquires specifically into the matter the case is not so clear. Let θ be the *difference* between the lags of the two telephones behind the electromotive force. Let L_1 and L_2 be their self-inductions, R_1 and R_2 their resistances. Let ω be proportional (2π) to the frequency of the note. Then as shown in my last paper,

$$\tan\theta = \frac{L_1\omega/R_1 - L_2\omega/R_2}{1+(L_1\omega/R_1)(L_2\omega/R_2)}.$$

The quantity $L_1L_2\omega^2/R_1R_2$ will usually be large as compared with 1. Thus

$$\tan\theta = (R_2/L_2 - R_1/L_1)/\omega.$$

Since, therefore, tan θ increases inversely with frequency, and since self-induction is not small as compared with resistance, θ

will not usually exceed a few degrees. Its effect will thus be negligible in view of the usually large values of ω.

Hence it seems more probable that the vibration figures of the two diaphragms are not identical, or that the mirrors do not (with increasing amplitude) move parallel to themselves. There would thus be a rotation of fringes, and the effect is accentuated with two telephones. A decision of the matter must, however, be reserved for stroboscopic work with spectrum monochromatic light.

4. Returning again to the small induction coil, I put an additional telephone in circuit, which throughout the experiment was held to the ear, and then inserted enough resistance (20,000 ohms with a weak primary current) to obtain vibrations only just discernible by the interference method. The effect in general is a widening of the bands (for the elongations are specially visible) together with a blurring of the field as a whole. Under these conditions I observed a permanent displacement of the fringes, which changed sign with the sign of the current, the shifting being about a half fringe or equivalent to 15×10^{-6} cm along the central normal of the diaphragm. The latter is thus more attracted in one case and less in the other, or the position of equilibrium of the vibrating plate does not apparently coincide with its position for no current. Hence the forced vibrations must have been more rapid than the natural frequency of the plate.

It is interesting to compute the increment of force tugging at the plate in these cases. Having given a circular plate of radius r and thickness s, fixed at the edges, the force P in dynes will produce a displacement of f centimeters, where

$$f=\frac{0\cdot6825}{\pi}\frac{r^3}{s^3}\frac{P}{E},$$

E being Young's modulus (2×10^{12} dynes). Putting $r=2^{cm}$, $s=0\cdot016^{cm}$, $f=15\times10^{-6}$ cm (as just found), the value of P becomes

$$P=140 \text{ dynes.}$$

This unexpectedly large result for the force at the center of the plate is an explanation of the unexpectedly small excursions of the diaphragm discussed above: for even if the given minimum amplitude of 10^{-6} cm be taken, the force at the center in case of static flexure would exceed 10 dynes.

Brown University, Providence, R. I.

Art. XXI.—*The Arctic Sea Ice as a Geological Agent;* by Ralph S. Tarr.

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Nature of Sea Ice.—Floating in the Arctic waters there are two kinds of ice—the sea-made, and the glacier ice. The former develops in the autumn, first freezing over the protected fjords and bays, and later covering the greater part of the Arctic sea. As it freezes it encloses the glacier ice and consolidates the entire water surface into one mass of ice, which remains in this state until spring. The sea-made ice attains a depth of only a few feet, averaging perhaps fifteen or twenty feet. The wind, waves and currents move it about somewhat even in the winter, and by breaking it and piling the fragments on one another make the surface very irregular, greatly increasing the depth of some of the cakes. Moved by the tides and winds, it grinds against the shore and the shallow bottom, thus doing much work of erosion. In the spring, under the warmth of the rising sun, it commences to melt and goes floating away to the southward, where it finally returns to the liquid condition. Then, hundreds of miles to the southward, the individual cakes and scattered floes may introduce the conditions of the ice-bound sea of the north into the southern latitudes even late in the summer.

Nature of Glacier Ice.—Near the glaciers which end in the sea, the surface of the fjords is littered with ice that has been derived from the glacier front. The melting in the warmth of the sun, the movement over an irregular bottom or the buoyancy of the water, make cracks in the glacier; and the action of the waves and sea water at its base undermines the ice cliff, so that there is a constant cracking and falling of bits and blocks of glacier ice. The air is constantly filled with the reports of varying intensity which accompany the breaking off of ice. Now and then a large piece, perhaps a great section of the glacier front, falls away and enters the sea as an iceberg.

This glacial ice, of whatever origin, encumbers the water of the fjords so that navigation even in a small boat is usually difficult. Slowly the ice drifts out to sea, for the summer winds prevail from the glacier-covered land, and hence there is a balance maintained. Were it not for these off-shore winds the glacier would soon fill the fjord with ice, and not being

able to discharge its cargo, would be obliged to push farther out to sea. The sea-ice is made in winter; the glacier ice is mainly supplied in summer. During the spring and early summer the movement of the sea-made ice is active, and then, when it has disappeared, its place is taken by the supply from the glacier.

Influence of sea-made ice on erosion.—The sea-made ice of winter, covering the bays from shore to shore, *protects* the coast from the action of waves, and hence for the greater part of the year prohibits this form of erosion. Even when the ice is broken up and floating away, it protects in nearly the same manner; for the ice cakes and floes prevent waves from forming, and destroy those that have already been formed elsewhere. Even when the wind was blowing, while our ship was in the open sea off the Labrador coast, there was only an almost imperceptible swell, the remnants of the nearly destroyed waves of the ice-free, open water. However, when the ice cakes are more scattered, the waves use them as effective tools, hurling them against the coast and grinding them up and down upon it. Moreover in the last stages a rim of ice clings firmly to the rock at high-tide mark, and no doubt the waves use this in places as a means of prying off fragments of rock.

It would be difficult to balance the protective and destructive action of this sea ice, but I believe on the whole that the average is in favor of protection. Nevertheless the ice is used as a very effective tool, not merely by the action of the waves, which hurl the individual blocks against the shore, but chiefly by the grinding action of the tide. As the water rises and falls the ice is constantly ground against the shore, and that as a result of this it is doing much work is oftentimes clearly illustrated. Nowhere was this better seen during my visit to the Arctic than on the southern side of Baffin Land in White Strait. There the tide rises about thirty feet, and the mud flats, when exposed to view at low tide, were seen to be pitted and gouged in a manner quite closely resembling the surface of the mud flats on the Massachusetts coast after the clam diggers have left them. Carried in by the tide, the ice cakes strike against the muddy bottom and dig a hole, thus stirring up considerable mud, which is driven about by the tidal currents. Stranded cakes were everywhere present, and that they were engaged in the transportation of rock material was often shown by the presence of good-sized bowlders, deeply embedded in the mud, where they had been dropped by the melting of the ice.

In this same region the grinding and transporting action of the ice was shown by the bowlder beaches. At the head of

narrow and perfectly protected bays, there were beaches of bowlders, averaging a foot or two in diameter, and beneath these, forming the bottom of the bay, was mud. No other agent than ice could possibly have placed these bowlders in this position, and upon the stranded blocks of ice there were some bowlders journeying toward the beach. Similar bowlder beaches were found in the valleys of the land, showing that when the land was formerly lower this same ice action was in progress.

There is another way also in which the sea ice aids in the work of erosion on the shores. The rocks of the New England coast are covered with a protective mat of seaweed, barnacles and other forms of life, while the Arctic shores are entirely free from this covering, except in the minute and most protected crevices. Because of the ice grinding on the shore, life is impossible in the intertidal zone, although at a short distance below this, both animal and plant life are extraordinarily abundant. Lacking the protection of this organic mat, the rocks are open to the direct attack of the water, and its agents must, therefore, work with greater rapidity, in a given period of time, than they do upon a similar coast that is protected by organisms.

Erosion by Glacier Ice.—In a less noticeable way the action of the glacial ice is the same. It is used in the same manner as the sea-made ice, and adds to its efficiency both in protecting and destroying; but there are two additional ways in which the glacier ice does work of erosion after it leaves the glacier. In order to understand the first of these it is necessary to know how the icebergs are put forth into the sea. So far as I could observe, there are several ways in which the ice comes from the glacier front. As has been said, some pieces, usually of small size, drop because of surface melting, and others fall because the sea undermines the ice cliffs. Besides these sources of glacier ice there is the effect of the water, which buoys up the front of the glacier until a breaking results, when bergs, usually of large size, proceed from the front of the glacier.

In some cases this process of iceberg formation happens very quietly, and the front merely cracks off and floats away; but much more commonly the breaking is accompanied by a very decided disturbance. The end of the glacier has attained an unstable position; melting or undercutting cracks off a fragment, and the accompanying jar causes others to follow. The air is filled with sounds, as if of musketry, and from the glacier front there is a constant shower of small pieces and large blocks. Whenever a great mass falls away, numbers of others equally large or larger follow very closely. These do not

break and float quietly away, but actually fall forward into the water. Even though the crack started from the bottom there is no other way for the bergs to fall than to go forward. They must then attain a stable position in accordance with their form, and this often causes them to roll over completely, and float away bottom side upward. So a newly-born iceberg may move off from the ice front either upon its side, bottom or top.

Not only are icebergs of massive form sent off from the glacier front, but if they come from a place that has been sufficiently crevassed and melted into irregular outline, the jarring caused by the falling and overturning may in the end completely destroy the berg and leave in its place only a multitude of fragments. One may often see an immense mass fall off from the ice front, and as it turns and rocks, may observe it break, until finally the original berg is entirely destroyed. When the iceberg is more solid, although numerous fragments continue to drop from its surface as long as it moves, it rocks and rolls backward and forward, perhaps for a half hour, before finally becoming quiet, and every piece that breaks off from this mass adds to the cause of rocking.

From the mass of ice thus cast off from the glacier there is sent outward a water wave, high near the ice front, but reduced to a low, almost imperceptible swell at a distance of a few hundred yards. Following this are other ring waves caused by the rocking and continued breaking. Though low, these are very powerful, for, like the earthquake wave, they are deep-seated disturbances, not superficial like the wind wave. When they reach the shore it is whitened by surf as long as the waves continue to arrive. Then, although the surface of the fjord rises and falls only very gently, the shore line resembles the storm-bound coast of the open ocean; and during a stay of several weeks in the fjord near the Cornell Glacier, at the base of the Upper Nugsuak peninsula (Lat. 73° 15′), these were the only good-sized waves that we saw, near the head of the bay. The waves caused by the production of bergs furnishes an additional instance of erosional work which Arctic ice does. Similar though smaller waves are formed when an iceberg runs aground and begins to break because of the jar.

When a berg comes off from the glacier it falls into the sea and rises and falls as it rocks backward and forward. Possibly as it moves it strikes the bottom; and certainly, as a result of the disturbance which it produces in the water, it stirs up the materials forming the bottom. After leaving the glacier front, in the course of its life history, the berg in all probability becomes stranded once or perhaps several times. Each time it touches the bottom it strikes a direct and heavy blow, and then, breaking slightly as the jar passes through it, and perhaps

even falling into fragments, it rocks backward and forward in its effort to regain a stable position, thus striking the bottom again and again, and undoubtedly stirring up much mud by means of the disturbance of the water. Even when not striking the bottom a strong wave is sent down to the bottom, and by this also there must be a disturbance. That these movements of the iceberg are performing work of distinct importance is proved by the muddiness of the water near the stranded bergs. Also in the berg fjords there is always the evidence of floating sea weed which has been detached from the bottom by this means.

In the fjord which I studied in most detail, an interesting adaptation of animal life to this phenomenon was observed. On the face of the nunatak between the two lobes of the Cornell glacier, a colony of gulls had their breeding place. The moment the report of a falling berg of large size passed through the air, these birds left the cliff, and the air was white with these graceful creatures, flying directly, and with much eager chattering, to the front of the glacier, where they settled on the surface of the water and obtained a feast of shrimp and mollusks which had been stirred up and raised to the surface on the detached sea weed. This grinding against the bottom, and the disturbance caused by the wave produced by the falling ice, not only does considerable work of erosion, but also destroys much life. Notwithstanding this constant destruction, and it is certainly very great, the fauna in the bottom of the fjord was found to be abundant and varied.

Transportation by Sea Ice.—The sea ice of all kinds is also doing a great work of transportation. During our voyage along the Labrador coast, we passed through an unusual amount of floe ice. Shortly after leaving the straits of Belle Isle, we encountered it, and were then in the ice almost continuously until we left the American coast a little north of Cumberland Sound. For nearly one thousand miles we were in sight of floe ice, and we therefore had unusually favorable opportunities for observing the conditions of this agent. As would be expected, the great number of floes were pure and white; but there were many that were transporting sediment. Even when the ice was freest from foreign materials it was estimated that about one per cent of the cakes carried debris of some kind. In some cases the ice was perfectly dirty and black with mud, so that at times we mistook cakes for seals and walruses. In other places, in smaller areas, fully fifty per cent of the floe ice in sight was discolored by a greater or less amount of detritus. These dirtier areas were undoubtedly derived from near the coast.

Some of the material that was being transported by the floe ice was very fine in texture, and apparently had been drifted upon the ice by the action of wind; but much of it was too coarse for this origin, and pebbles were frequently seen upon the surface of the cakes. No doubt these coarser materials were in part raised from the shore by the ice as it came in contact with the coast, or passed near it; but probably the material was more commonly furnished by rills and streams from the land. I am certain that in the distance of one thousand miles of ice-covered sea, our ship was within sight of thousands of tons of sediment, which was of course being slowly distributed over the bottom of the sea as the ice drifted southward.

Transportation by Glacier Ice.—Not merely is the floe ice carrying much sediment, but notwithstanding the statements of others to the contrary, the glacier ice is also a very potent agent in this respect. Among the bergs seen in the south it was rare to find one that had sediment in sight; but no doubt these, which had been floating for months, or possibly years, had long since given up their rock-burden to the sea. Along the Greenland coast, however, sediment-laden bergs were abundant, and this was particularly true in the fjords near the glaciers.

The sea face of the Cornell glacier, like that of most others on the Greenland coast, is made of clear ice, almost absolutely free from even the finest sediment, excepting near the land margin, and below the nunatak which furnishes a medial moraine. The same is true of the ice face wherever the glacier ends on the land; but near the glacier bottom, both on the land and in the fjord, the ice bears considerable debris. That this was true of the ice bottom in the fjord was proved by the evidence of dirt and bowlder-covered fragments that were floating in the water of the fjord. Some of these were entirely black, and we mistook some low ice masses for islands because of their discoloration. Moreover in one of the bergs which was actually seen to come from the ice front, this fact was definitely proved; for when it came off it turned with its bottomside uppermost, and floated away as a dark, discolored fragment, derived from a glacier whose exposed front was remarkably white.

There are thousands of tons of bowlders, gravel and clay sent into the sea from the front of the Cornell glacier every year and much of this passes beyond the fjord out into Baffin's Bay. The sediment supplied to Baffin's Bay is in no small part derived from the bergs that are discharged into it. Some of this may go for long distances, provided the berg is turned bottom side up, although even in this case the water furnished by the melting of the surface of the ice will after awhile wash

the sediment away. When the berg keeps rightside up, as is commonly the case, the debris rapidly escapes into the sea; and before the iceberg has moved far on its journey only clear ice, which of course forms the greater part of the mass, remains to float away. This is no doubt the reason why the southern bergs, even when these have recently turned upside down, as is frequently the case, are found to be free of sediment. They may have started on their journey with tons of debris.

Effect on Climate.—This brief statement of the geological effects of the Arctic ice would not be nearly complete if its effect upon the temperature of air and water were not mentioned. It chills the ocean on the American side, where the movement of the currents is toward the south, and by this means lowers the mean annual temperature of Baffin Land, Labrador and even New England, as everyone knows. In 1896 this effect was very clearly shown. An unusual amount of floe ice in the month of July so chilled the water on the Labrador coast, that the cod fisheries were nearly a failure, because the cod fish would not come into the cold water near the coast. It was also most strikingly shown in early September, when we left the Greenland coast in summer weather, proceeded toward the southwest, and as our first view of the Baffin Land coast saw a snow-covered land. An ice-covered country was warmer than a nearly ice-free land, which, however, was bathed in water that had been chilled by the ice of the Arctic.

Cornell University, Ithaca, N. Y.

ART. XXII.—*Contribution to the Geology of Newport Neck and Conanicut Island;* by W. O. CROSBY.

THE granite of Newport Neck and Conanicut Island was regarded by C. T. Jackson* as intrusive, and as having altered the Carboniferous shales to siliceous and epidotic slates. Edward Hitchcock† held a similar view; while C. H. Hitchcock‡ has described the granite as post-Carboniferous, and the siliceous slate as intermediate in age between the Carboniferous and the granite.

In 1876, while collecting data for the Centennial Geological Map of Massachusetts, I made a hurried examination of the Newport area, reaching the conclusion that the granitic rocks are more recent than the flinty slates, which they freely intersect, and older than the grits, shales, and conglomerates of the Carboniferous series; and provisionally correlating the flinty slates with the Cambrian beds of the Boston basin. These unpublished views concerning the relative ages and relations of the rocks and the essential distinctness of the flinty slates and the Carboniferous series were fully confirmed by a more detailed study made ten years later, in 1886, in company with G. H. Barton.

Meanwhile, in 1883 and 1884, T. N. Dale§ had made his important contribution to the geology of this region, in which he clearly recognized the three distinct series of rocks, but failed to regard the granite ("protogine") as intrusive in the flinty slate, making it the oldest of the three series. Three years ago (1893) L. V. Pirsson‖ studied the rocks of Conanicut Island, apparently paying no attention to the similar formations on Newport Neck, and reached the conclusions that the granite is the youngest rock formation on the island, that it is intrusive in the Carboniferous strata (shales) and that the flinty slate is merely a contact zone between the granite and shales, a portion of the shales which have suffered contact metamorphism through the influence of the granite and show a gradation from the most typical hornstone into unaltered fissile shales. Still more recently (1894) Collie¶ has published a somewhat elaborate account of the geology of Conanicut Island, in which he agrees with Dale in regarding the flinty slate as distinct from the Carboniferous series and older than the granite.

Since the publication of Pirsson's paper, I have desired to re-examine the relations of the granite to the sedimentary

* Geol. Survey R. I., 1840, 40, 89–92.
† Geology of Massachusetts, 1841, 537, 540, 550, 552.
‡ Proc. Amer. Assoc. Adv. Sci., 1860, 119, 121–126, 129–133, 136–137.
§ This Journal, III, xxvii, 217–228, 282–291. ‖ Ibid, III, xlvi, 363–378.
¶ Trans. Wis. Acad. Sci., x, 199–230.

rocks, but have only recently had an opportunity to do so.* That the granite is, in part at least, intrusive in the flinty slate appears to me unquestionable. Pirsson has clearly set forth the evidence for Conanicut Island, showing conclusively that the finer grain of the granite near the contact, the fact that it is at all points firmly welded to the flinty slate, and above all the fact that it forms beautifully clear apophyses and dikes in the latter, admit of no other explanation. Dale appears to have overlooked the fact that the evidence is similar and equally conclusive on Newport Neck. Dale's map of the

FIG. 1.—Map of Newport Neck and Conanicut Island, modified from Dale.

Neck, reproduced here (fig. 1), is substantially accurate. Along the north-south contact of the granite and flinty slate the fine-grained border of the granite is firmly welded to the slate and clear dikes of similar granite traverse the slate in the vicinity of the contact. The fine-grained, reddish, aplitic granite, whose igneous relations to the flinty slate are so unequivocal, is but the marginal portion or contact zone of a large body or massif of normal, coarse-grained, gray granite. Prof. Barton and I found, however, some evidence of the existence in this region of granitic rocks older than the flinty slate. This evidence consists in the occurrence in the flinty slate, on the north shore of the neck, of several layers of conglomerate containing gray granite pebbles. That the flinty slate owes its

* In this later study I was assisted by Mr. T. A. Watson.

flinty or metamorphic character to the influence of the granite is obvious, and it undoubtedly shows some gradation in the degree of metamorphism as we recede from the border of the granite. But that it grades into the highly fissile Carboniferous shales, as held by Pirsson, cannot be admitted. This is the most critical and at the present time the most distinctly controverted point in the geology of the region. According to Jackson and Pirsson this gradation exists; the flinty slate is simply a more altered part of the Carboniferous shales, and the granite is post-Carboniferous; while according to Dale and Collie the flinty slate is distinctly older than the Carboniferous series, Dale's view differing from that of Collie and the present writer only as regards the relations of this older flinty slate to the granite.

On Newport Neck the flinty slates and the Carboniferous shales are certainly very strongly contrasted, both lithologically and stratigraphically. The former are exceedingly massive gray rocks of almost flinty hardness, rarely exhibiting anything approaching a thin-bedded or shaly structure and with a prevailing east-west strike and approximately vertical dip. The latter are soft, fissile, greenish, greenish-gray or purplish shales with a prevailing north-south strike and moderate easterly dip. Each series holds its characters perfectly up to the common boundary, which is a very obvious fault line. From the granite westward to this line the metamorphic character of the flinty slate diminishes so slightly as to suggest that the granite may underlie the entire area at no great depth. The flinty slates, owing to their superior hardness, form, like the granite, a broken and ledgy tract, which rises boldly above the low and swampy ground underlain by the shales. The stratigraphic discordance is perfect, and indications of a lithological gradation are wholly wanting, although it might be claimed, since the nearest outcrops are thirty feet apart, that a very abrupt gradation is still a possibility. The Carboniferous age of the shales is unquestioned, while it may safely be asserted that the flinty slate resembles no other formation in New England so closely as the Middle Cambrian slates of the Boston basin, many of the ledges being indistinguishable from the more characteristic outcrops of the Blue Hills.

These phenomena are repeated in all essential features at the south end of the Cliffs, between Sheep Point and Bailey's Beach. In going south along the east shore we pass abruptly, near Sheep Point, from Carboniferous shales that are in part greenish gray and in part black and highly carbonaceous, affording an abundant Carboniferous flora, to a compact greenish to grayish tough rock, with occasional bedding lines and streaks of conglomerate, which is undoubtedly equivalent to the flinty slate of Newport Neck. About half way from

Sheep Point to Coggeshall's ledge we pass from the metamorphic slate to the granite. The contact is beautifully exposed and typically igneous, the granite being clearly the newer rock. The granite is bordered by a felsitic or microcrystalline layer four to six inches wide penetrating the slate very irregularly, and forming numerous dikes six inches to three feet wide. The two rocks are firmly welded together. Following the granite around the shore to Bailey's Beach, we come again, at the east end of the beach, upon the metamorphic slate; but the contact is not exposed, what Dale has described as a contact being, apparently, a dike of greenish slaty trap in the granite. The north-south strike and high dips of the unaltered Carboniferous strata north of Sheep Point suggest a northeast-southwest fault between the older and newer slates almost as plainly as on Newport Neck.

On Conanicut Island the metamorphism of the ancient slate series is more marked near the granite, and there is a more distinct gradation in metamorphic character, than on Newport Neck. We pass from the granite to a massive semicrystalline greenish rock, almost destitute of recognizable bedding lines and netted with veinlets of quartz and epidote. This grades into the normal flinty slate similar to that of Newport Neck, which is in part distinctly bedded, with approximately east-west strike and vertical dip. Pirsson states that "every transition can be found between unaltered shales and the most solid of hornstones in contact with the granite, but not, however, in any one place or exposure." I find, on the contrary, that, so far as the shales are concerned, they show absolutely no gradation in the degree of metamorphism along lines normal to the border of the granite; and the metamorphism is quite as marked miles away from the granite as in its vicinity. The drift mantle north of the granite and metamorphic slate is practically continuous from shore to shore; and Pirsson is able to point out only one exposure where the supposed gradation of the shales into the typical flinty slate or hornstone can be observed. He says: "In the northeast (printed northwest) corner of D 5 (figure 2) just south of Mr. Green's barn occurs a long outcrop extending toward the south. At the north end the shales, although still retaining a fissile character, are very much gnarled and toughened, and as one proceeds southward they pass within two or three rods into compact hornstones. From this exposure it may be seen that the loss of the shaly character and transition into hornstone occurs within a very short distance." I have closely scrutinized this outcrop; but find myself unable to accept Pirsson's interpretation of it. It seems to me to belong wholly to the flinty slate, the supposed gradation being simply one of the many local variations of this formation. But even in this sense I can see no real gradation.

From the north end of the ledge southward the slate is rather unusually but uniformly shaly for about twenty feet, and then we pass with absolute abruptness to the most typical tough, massive, and seemingly unstratified hornstone, which forms all

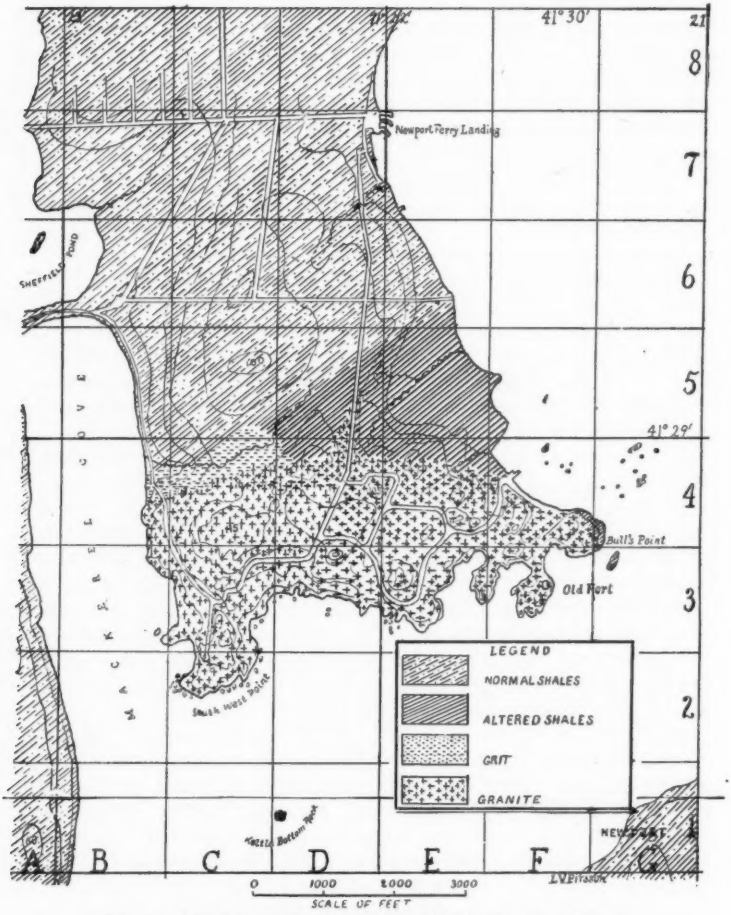

FIG. 2.—Map of a part of Conanicut Island, by L. V. Pirsson.

the remainder of an extensive outcrop. The abruptness of this passage from the less to the more metamorphic slate suggests a small fault. This outcrop is about one thousand feet from the nearest exposure of granite, and nearly two thousand feet from the main body of granite; and it certainly seems improbable that the metamorphic influence of the granite,

having extended so far with approximately uniform intensity, should then die out or show a very marked diminution within a few feet or yards. A rapid change near the granite and a slow change at a distance would appear to be a better expression of the general law in such cases.

Considered by itself, this evidence is, perhaps, inconclusive, since to the northward there are no outcrops for a long distance. But it is important here to take note of the bed of arkose (called grit by Pirsson and quartz and clay aggregate by Dale) which Dale, Pirsson and Collie have mapped on the east shore of Mackerel Cove, between the granite and shales (figure 2). Each of the maps referred to shows the arkose, which has a breadth on the shore of at least 400 feet, as extending in a northeasterly or diagonal direction toward the eastern shore of the island, and ending abruptly with a greatly increased breadth when less than half way across the island. After examining the outcrops of arkose on the shore of Mackerel Cove, Mr. Watson and I were searching along the road north of Mr. Green's barn for outcrops, hoping to find something that might assist in the interpretation of the outcrop upon which Pirsson's argument so largely rests, when our attention was attracted by the abundance of arkose, identical in character with that on the shore, in the stone walls and scattered in angular masses up to three feet in diameter over the adjoining fields. Following up this clue, we found that the arkose debris is abundant over the entire slope from the road to the east shore for a breadth of 400 to 500 feet north of the last outcrops of the flinty slate; and on the shore, from the flinty slate on the south to the green and fissile shales on the north, an estimated distance of four hundred feet, there are many angular masses of the same coarse, dark arkose. In the light of these facts it cannot be doubted that the arkose extends entirely across the island in a belt of approximately uniform breadth (four hundred feet more or less) between the unaltered green shales on the north and the flinty slate and granite on the south (fig. 1). Its unconformable relations to these older rocks is indicated by its passing obliquely from the one to the other.

This continuous belt of arkose separating the flinty slate from the unaltered green shales seems to materially strengthen the conclusion stated above with regard to the significance of the ledge south of Mr. Green's barn. The idea of an important or significant gradation is ruled out for the simple reason that there is nothing for the flinty slate to grade into. The arkose is quite out of the question in this connection, if for no other reason, because it is so clearly newer than the granite of the debris of which it is chiefly composed, and, therefore, newer than the metamorphism of the flinty slate which the granite intersects. That the arkose is not a fault-breccia, but a

regular member of the Carboniferous series, seems to be proved by the following considerations: First, it is composed chiefly of granite debris and not of fragments of shale, as it undoubtedly would be if due to the mutual friction of the granite and shale. Second, it is essentially identical with the arkose which elsewhere in the Narragansett Basin clearly underlies the green and gray shales, as on Rose Island, Coasters Harbor Island, and Sachuest Neck, and on the mainland at Tiverton and Fall River; and is quite certainly, as held by Dale, Collie, and others, the basal member of the Carboniferous series. Collie says, "the arkose (of Conanicut Island) is not a local exposure. It is everywhere present, lying between the granite and the overlying schist (shale). Well-diggers state that in all parts of the island they invariably come upon a layer of rotten granite before the hard granite is reached."

The arkose clearly follows the northern border of the granite and flinty slate, cutting across the north-south strike of the shales. This marked discordance of the arkose and shales suggests a northeast-southwest fault between them, with the downthrow on the northwest. Of this fault we have abundant evidence on the shores, and especially on the eastern shore, where we find between the arkose and shale a magnificent development of fault breccia. For a breadth of about fifty feet the green and black shales are completely brecciated, the fragments being cemented by an imperfectly lithified argillaceous paste; and north of this crushed zone are many minor shear planes approximately parallel to the main fault and transverse to the strike of the shales. This great fault evidently belongs to the same system as those on Newport Neck, the chief difference being that in the case of the latter the upthrow has been sufficient to carry the arkose wholly above the present plane of erosion. The relations of the arkose on Conanicut Island point distinctly to the conclusion that the faults date from the time when the Carboniferous strata were folded and the rigid floor of granite and flinty slate was upheaved, that is, during the Appalachian revolution.

Concerning the southwest extension of this fault nothing can be positively asserted. The non-occurrence of the ancient slate and granite on the Beaver tail portion of the island suggests a fault parallel with the major axis of Mackerel Cove. The trap (minette) dikes (fig. 1), as Collie has pointed out, cut both the granite and the shales, and must be post-Carboniferous, probably dating, like the great dikes of the Paradise Rocks, from the folding and faulting of the strata. This completes the parallelism with the geology of the Boston Basin, where the granitic rocks—granite, diorite, and felsite—are clearly newer than the Cambrian slates and older than the Carboniferous strata, and the trap dikes are post-Carboniferous, except a few which antedate the granite.

Art. XXIII.—*The Estimation of Molybdenum Iodometrically;* by F. A. Gooch.

[Contributions from the Kent Chemical Laboratory of Yale University, LXII.]

In a former paper from this laboratory* several modes of applying hydriodic acid to the reduction of molybdic acid were studied. It was found, first, that the digestion process of Mauro and Danesi† is of very limited applicability, owing to the fact that the reaction of reduction is reversible. Secondly, it appeared that the use of the same reaction by Friedheim and Euler‡ in a distillation process, so arranged that the iodine set free in the reduction might be caught in the distillate and titrated to serve as the measure of the reducing action, was not sufficiently regular because of inattention to minor details. It was shown that by taking care to adjust the conditions constant results might be obtained. Thirdly, the fact was developed that by simply boiling the solution under well defined conditions in an ordinary Erlenmeyer flask, partly closed by a simple trap, the reduction of the molybdic acid proceeded regularly, and that the addition of standard iodine to the solution made alkaline with sodium bicarbonate served to restore the original condition of oxidation of the molybdic acid. The results of this treatment were shown to be accurate.

In a recent paper§ Friedheim has seen fit to make our modifications of the distillation process the subject of attack. Friedheim's comments upon the third method discussed (as well as upon a subsequent application of the process)‖ are evidently prompted wholly by personal opinion and demand no further attention. With reference to Friedheim's denial of the necessity of modification in the Friedheim and Euler treatment the case is different.

The process of Friedheim and Euler consists, it will be remembered, in treating the soluble molybdate, or the solution of molybdic acid in sodium hydroxide, with potassium iodide and hydrochloric acid in a Bunsen apparatus, boiling until the solution is of a clear green color, collecting the iodine distilled in potassium iodide, and titrating it with sodium thiosulphate. We found that the development of the green color was not a sufficient criterion of the exact reduction of the molybdic acid to the condition of the pentoxide and of the removal of the iodine which should be theoretically set free. To accomplish that end we found it safer and more convenient to

* Gooch and Fairbanks, this Journal, IV, ii, 157, 1896.
† Zeitschr. für anal. Chem., xx, 507. ‡ Ber. d. d. Chem. Gesell., xxviii, 2066.
§ Ber. d. d. Chem. Gesell., xxix, 2981.
‖ An Iodometric Method for the Determination of Phosphorus in Iron, by Charlotte Fairbanks.

start the distillation with a definite volume (40$^{cm^3}$) of liquid and boil until a definite volume (25$^{cm^3}$) was reached, care being taken with regard to the strength of acid and the excess of potassium iodide employed. Experience showed unmistakably that in order to avoid the decomposing action of the air upon the hot vaporous hydriodic acid in the retort, it was necessary to go beyond the measures advised by Friedheim and Euler (namely, to warm the retort and its contents slowly, heating to boiling only when the connecting tube was well filled with iodine vapor and the tendency toward back-suction of the liquid in the receiver began to appear) and to conduct the operation in a simple little apparatus (the retort holding about 100$^{cm^3}$) put together entirely with sealed and ground joints, as shown in the figure of the former paper, so arranged that a current of purified carbon dioxide could be passed through retort and receiver during the distillation. With this apparatus we were able to determine with accuracy the point of concentration at which the free iodine left the liquid, the molybdic acid having been converted to the condition of the pentoxide. It was found that if dependence is placed upon the occurrence of the so-called clear green color of the liquid to determine the end of the distillation, it may frequently happen that free iodine remains in the residue. This takes place, it will be observed, in the atmosphere of carbon dioxide, so that the presence of the free iodine can by no possibility be attributed to the action of atmospheric air upon the hydriodic acid remaining after the distillation is complete. On the other hand, it appeared that, if the distillation is pushed too far, the molybdenum pentoxide may be still further reduced with consequent evolution of more than the expected amount of iodine. The attainment of an exact degree of reduction with the expulsion of the corresponding amount of iodine becomes, therefore, a matter of chance unless further precautions are taken. We found in our experiments that, if amounts less than 0·3 grm. of the molybdic acid are introduced in soluble form into the 100$^{cm^3}$ retort with a not too great excess of potassium iodide, and the 40$^{cm^3}$ of liquid so constituted that 20$^{cm^3}$ of it shall be water and 20$^{cm^3}$ the strongest hydrochloric acid, the reduction proceeds with a fair degree of regularity in the manner expected. We found it important to restrict the excess of potassium iodide so that it shall never exceed the theoretical requirement by more than 0·5 grm.

Our determinations with the pure molybdenum trioxide showed errors varying from ·0010 grm. + to ·0007 grm. − ; the variations from theory in the experiments with ammonium molybdate ranged from ·0011 grm. + to ·0011 grm. −. If these results are compared with those given by Friedheim and Euler, the advantage is a little in favor of the latter ; but a

scrutiny of the figures given by Friedheim and Euler developes the fact that the apparent accuracy of their work is founded upon miscalculations. This fact was known to us at the time of our former writing, but we did not consider it essential then to make the matter public. The recent attack of Friedheim makes that course now necessary.

Herewith is reproduced a table of results obtained by Friedheim and Euler in the test of their method upon ammonium molybdate, shown by analysis to contain 81·49 per cent. of molybdenum trioxide. The figures which are incorrect are enclosed in brackets:

Original Figures of Friedheim and Euler.

Molybdate taken. grm.	$Na_2S_2O_3$ used. cm^3.		MoO_3 found. grm.	Per cent of MoO_3 referred to molybdate taken.
0·2674	30·8	1 cm³ = 0·00709 MoO_3	0·2184	[81·71]
0·4418	50·8		0·3601	81·51
0·4075	[40·7]*		0·3317	81·40
0·3281	37·33	1 cm³ = 0·007086 MoO_3	0·2644	[81·85]
0·4340	49·43		0·3502	[81·69]
0·4098	46·63		0·3304	[81·67]
0·4305	49·08		0·3478	[81·78]

Appended is a recalculation of the percentage of the trioxide found, with columns showing the percentage error and the error stated in fractions of a gram. Changes from the figures of Friedheim and Euler are in heavy-faced type.

Recalculation of the Results of Friedheim and Euler.

Corrected per cent of MoO_3 found, referred to the molybdate.	Error in per cent of MoO_3 found compared with MoO_3 taken.	Error of MoO_3. grm.
81·68	0·23+	0·0005+
81·51	0·03+	0·0001+
81·40	0·12—	0·0004—
80·58	1·12—	0·0030—
80·69	0·99—	0·0035—
80·62	1·05—	0·0035—
80·79	0·86—	0·0030—

These figures of their own (properly calculated) are sufficient to show the inadequacy of the method of Friedheim and Euler. We ourselves were occasionally able to get results from the method of Friedheim and Euler quite as good as these; it must be said, however, that most of our results

* Probably 46·7.

obtained by their unmodified method have been even worse than their own.

In another series of six determinations, in which molybdenum trioxide was the starting point, Friedheim and Euler were more successful, the errors varying from 0·0006 grm. + to 0·0006 grm. −. Thus Friedheim and Euler establish by their own results the fact that the hitting of the right point at which to stop their process of boiling is a matter of chance. In spite of the probability that some of the iodine which they found in the receiver was liberated by atmospheric action, the fact remains that their results are in many cases very low. That is, they did not boil long enough.

The difficulty appears again in the modification of their method which Friedheim and Euler apply to the determination of molydenum trioxide associated with vanadium pentoxide*, namely, the distillation with phosphoric acid and potassium iodide of the residue left after reducing the vanadium pentoxide by hydrochloric acid and potassium bromide, according to the method of Holverscheit. We reproduce the part of their table which refers to the determination of the molybdenum, adding, however, columns containing the errors and corrected percentages.

MoO_3 taken.	MoO_3 found.	Per cent MoO_3 F. and E.	Error. grm.	Per cent MoO_3. Recalculated.
0·15037	0·15005	99·79	0·00032−	99·79
0·16895	0·16879	99·90	0·00016−	99·90
0·17758	0·17729	99·84	0·00029−	99·84
0·24975	0·24962	99·95	0·00013−	99·95
0·33151	0·33607	[99·87]	0·00456+	**101·38**

Four of the five determinations are accurate, but the fact that all figures are carried out to the fifth decimal place does not keep three good sized figures out of the error column for the fifth determination.

It is hardly necessary, in the light of a comparison of the results of Friedheim and Euler with ours, to discuss further the unreliability of the unmodified process. The necessity of a proper control of the volume, strength of acid, and excess of potassium iodide, as well as proper protection from atmospheric oxidation, is real.

On a former occasion the unpleasant necessity presented itself† of pointing out the fact that certain unfounded criticisms on the part of Friedheim and Meyer were based upon an unfortunate use by them of impure reagents; the difficulty in the present case, for Friedheim and Euler, seems to reside in the arithmetical process.

* Ber. d. d. Chem. Gesell., xxviii, 2072.

† Gooch and Browning, this Journal, xlv, 334.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Density of Helium.*—Ramsay has continued his researches on the gaseous constituents of minerals. While the gas from clèveite contains some nitrogen and no hydrogen, that from bröggerite, samarskite and fergusonite, obtained by heating the mineral in a vacuum, is rich in hydrogen but contains only an infinitesimal amount of nitrogen. From one gram of clèveite 7·2^{cc} of helium were obtained; while from one gram of bröggerite less than 1^{cc}, from one gram of samarskite only 0·6^{cc} and from fergusonite (by heating alone) only 1·1^{cc} per gram were obtained. This latter gas contained hydrogen 54·7, carbon dioxide 13·9 and helium 31·2 per cent. For the density determinations the gas was purified by treating it with caustic soda and then passing it over red hot copper oxide, soda-lime and phosphoric oxide. The helium from bröggerite and clèveite mixed had a density of 2·218; and after a second treatment one of 2·133. That from bröggerite alone gave 2·181. That from samarskite, obtained by heat alone, 2·121; obtained by fusion with $HKSO_4$, 2·122; falling to 2·117 after a second treatment, and to 2·114 after a third one; the mean being 2·118. The gas from fergusonite obtained by heat alone gave in one sample 2·147, in another 2·139 and in a third 2·134; the mean being 2·140. It may be, therefore, that helium from various sources is not quite homogeneous, different samples varying in density. The light given by a vacuum tube containing clèveite gas has a richer orange-yellow shade than that from the other three minerals. Moreover this clèveite gas shows a special set of fairly strong lines between the green and the blue which have never been observed in the gases obtained from the other minerals.—*Proc. Roy. Soc.*, lix, 325, 1896. G. F. B.

2. *On the expansion of Helium and Argon.*—By means of thermometers containing air, hydrogen, argon and helium respectively, Kuenen and Randall have determined the relative coefficients of expansion of these gases, at the temperatures of the melting point of ice, and the boiling points of water, chlorbenzene, aniline, quinolene, and bromnaphthalene. The helium used had a density of 2·13, and the argon, which was prepared from air by means of magnesium, a density of 19·99. From the pressure readings at 0° and at 100°, the mean coefficient for helium between these limits was found to be 0·003665, for argon 0·003668, and for air 0·003663. Using these figures, the authors calculated the boiling points of the other substances above mentioned and found them to accord closely. Though no very high precision is claimed for these results, they serve to show that argon and helium may be regarded in so far as perfect gases.—*Proc. Roy. Soc.*, lix, 198, 1896. G. F. B.

3. *On the electric discharge in Argon and Helium.*—Experi-

ments have been made by COLLIE and RAMSAY to determine: 1st, the distance through which the electric spark will strike through argon and through helium at atmospheric pressure; and 2d, the pressure under which the spark discharge changes into a ribbon-like discharge in these gases, as compared with others. Even with argon it was found that the length of the spark was considerably greater than with air, oxygen or hydrogen; while with helium the distance through which the spark would pass was remarkable. Thus while in oxygen the spark-length was $23{\cdot}0^{mm}$, in air $33{\cdot}0^{mm}$ and in hydrogen $39{\cdot}0^{mm}$, in argon it was $45{\cdot}5^{mm}$ and in helium probably 250–300^{mm}. In helium the discharge was a blue ribbon of flame not showing the D_3 line very distinctly. Moreover these experiments showed that the spark discharge changed to the ribbon discharge at some definite pressure in all gases. Thus in air it occurred at 73 or 74^{mm}; in hydrogen at 42 or 43^{mm}; in oxygen at 81^{mm}; in carbon dioxide at 92 or 94^{mm}; in cyanogen at 23^{mm}; in nitrogen at 33^{mm}; in carbon monoxide at 49^{mm}; and in helium at 1270^{mm}. Hence helium is different from all other gases in this respect. So that a Plücker tube filled with helium at atmospheric pressure exhibits all the phenomena of a vacuum tube.

In a second series of experiments, made in electrodeless tubes, at different pressures, the object was to determine the quantity of one gas detectible in a mixture with another, and thus to form a judgment as to the adequacy of the spectrum test as an evidence of purity. In hydrogen it was found that at $2{\cdot}61^{mm}$ 33 per cent of helium was quite invisible, while at the lowest pressures 10 per cent was barely visible. Conversely 0·001 per cent of hydrogen is visible in helium at all pressures. Nitrogen 0·01 per cent is almost invisible in helium; while 10 per cent of helium in nitrogen can be detected only with difficulty. Argon 0·06 per cent can be detected in helium at all pressures; while 33 per cent of helium is invisible in argon at $2{\cdot}62^{mm}$ pressure and 25 per cent is invisible at $0{\cdot}58^{mm}$. Nitrogen 0·42 per cent is invisible in argon at $0{\cdot}17^{mm}$ pressure and 0·08 per cent is invisible at $0{\cdot}18^{mm}$, although just visible at $1{\cdot}05^{mm}$. Argon 37 per cent in nitrogen is barely visible at any pressure; while in oxygen 2·3 per cent can be distinguished only with difficulty at $1{\cdot}04^{mm}$. The luminosity of the argon spectrum is greatly decreased by oxygen, the reduction of pressure having no effect in intensifying it.—*Proc. Roy. Soc.*, lix, 257, 1896. G. F. B.

4. *On the Gases obtained from Uraninite and Eliasite.*—Observations by LOCKYER show that the gases obtained from the mineral eliasite when heated in a vacuum yield spectra containing the lines of unknown elements as well as of known ones, many of these being probably coincident with stellar and solar lines, although in somes cases no coincidences have been observed. He observes that the composition of the gas varies with the stage of the heating process, no trace of D_3 being seen in the first two portions taken, while in the third from the same specimen this

line was quite bright. Indeed in one experiment the product of this heating collected in four stages gave different spectra. The spectrum of the gas from eliasite contains lines indicating a new gas, thus resembling brŏggerite and clèveite. The fact that D_3 is not necessarily present would seem to favor the view that the gases from these minerals are complex.

As to uraninite, Lockyer has brought together his notes on the spectra of the gases obtained from this mineral. In addition to the hydrogen lines, he has found in the spectra of these mineral gases all those of the chromospheric lines in Young's list which have a frequency of 100. From wave-length determinations which he has made, he has but little doubt as to the coincidence of several lines in the spectra of these new gases with lines appearing in the chromosphere, the nebulæ and the white stars. Probably too some often observed lines, not so far identified, belong to gases in the chromosphere not hitherto recorded. Since, as the result of diffusion experiments made on cléveite gas at different pressures, Runge and Paschen concluded that the gas giving the line D_3 was heavier than that giving the line 5015·7, the author regarded it as important for stellar classification to settle the matter and has made experiments in which the pressures were maintained the same. He concludes that if a true diffusion of one constituent takes place, the component giving D_3 is lighter than the one giving the line of wave length 5105·7; this being in harmony with solar and stellar results.—*Proc. Roy. Soc.*, lix, 1–3, 4–8, 342–343, 1895–6. G. F. B.

5. *On the preparation of Lithium and on a quick Nitrogen Absorbent.*—It has been shown by Warren that if dry lithium hydroxide is heated in an iron tubulated retort, and metallic magnesium is added from time to time in small pieces through the tubulure, metallic lithium distils over. If the carbonate be used, the metal obtained is contaminated with the carbide, which evolves acetytene in contact with water. The author also points out that a material absorbing nitrogen with great avidity and therefore of use in preparing argon from the air, may be obtained by reducing in an atmosphere of hydrogen and at as low a temperature as possible, a mixture of magnesium powder and calcium or barium hydroxide saturated with a strong solution of lithium.—*Chem. News*, lxxiv, 6, July, 1896. G. F. B.

6. *On the Artificial Production of Diamonds.*—By carburetting iron, fusing it in the electric furnace and allowing it to fall into mercury 10^{cm} deep covered with a layer of water 20^{cm} thick, Moissan has obtained granules of irregular shapes and also spheres or ellipsoids, both saturated with carbon. While however the former contained no carbon of high specific gravity, the latter contained both black and transparent diamonds, some of which, though microscopic, showed remarkably regular crystalline forms. Subsequently larger masses of the carburetted and fused iron were allowed to fall into water and mercury at the bottom of a pit-shaft 32 meters deep. But these conditions were not

favorable to the production of spherical masses of iron. When the falling globules touched the tub containing the mercury, or the earth outside, they broke up with a flame into scintillating globules giving a report like a rifle. When the fused carburetted iron was run into a small cylindrical cavity in a large mass of iron or copper, the fused metal was very rapidly cooled and diamonds were obtained mixed with graphite, the yield however being small. Moissan has also observed that the so-called black diamond, included in transparent diamonds from Brazil, is a variety of carbon differing from the diamond. When such diamonds are pulverized and heated in oxygen at 200° below the ignition-point of the diamond, the black matter burns away, leaving the residual diamond white.—*C. R.*, cxxiii, 206, 210, July, 1896.

G. F. B.

7. *On the preparation of Metallic Hydroxides by Electrolysis.*—Experiments by LORENZ have shown that metallic hydroxides can be easily prepared by electrolysis. The bath used is an aqueous solution of potassium or sodium chloride, sulphate or nitrate, according to the ease with which the desired hydroxide is formed in these solutions. A platinum plate constitutes the cathode, and a plate of the metal whose hydroxide is to be obtained, the anode. By stirring constantly the solution, the hydroxide comes down as an insoluble precipitate. Thus an anode of copper in potassium chloride solution gives a yellowish-red precipitate of cuprous hydroxide, while in a solution of potassium nitrate it yields a blue precipitate of cupric hydroxide. In this way the hydroxides of silver, magnesium, zinc, cadmium, aluminium, lead, manganese and iron are readily obtained. Mercury in a bath of potassium chloride gives no precipitate, calomel being formed; but in a bath of the nitrate, a black precipitate is produced. Thallium in baths of potassium salts is covered with suboxide, a brown precipitate of hydroxide being gradually formed. Tin in a bath of chloride, sulphate or nitrate yields orthostannic acid, which is thus easily obtained pure. Antimony and bismuth thus treated become covered with a grey coating, no hydroxides resulting. Nickel in a nitrate bath, is quickly covered with a black coating; but in a chloride bath the green hydroxide is easily obtained. Since the method is applicable to the preparation of hydroxides insoluble in water, the hydroxyl ions and the metal ions being formed in equivalent proportions, the hydroxide is obtained in neutral solutions; a great advantage over the chemical method, in which it is necessary to wash the hydroxide free from alkali. Moreover as the precipitated hydroxides are formed in the solution and not at the electrodes, the latter do not become foul and a large quantity of the product can be prepared with the same strength of current and solution. Evidently the anode should be made of pure metal in all cases.—*Zeitschr. Anorg. Chem.*, xii, 436, July, 1896. G. F. B.

8. *On "Excited" Metals, and on Excited Aluminum as a Reducing agent.*—A metal the activity of which is increased by

contact with another metal WISLICENUS proposes to speak of as an "excited" metal, in place of "metal couple" suggested by Gladstone and Tribe. To excite aluminum with mercury, aluminum powder is covered with a one-tenth saturated solution of mercuric chloride in absolute alcohol; and after a few seconds the product is washed with absolute alcohol and ether. Such excited aluminum is especially adapted for reduction in neutral solutions; an aqueous alcoholic solution of nitrobenzene yielding aniline in this way, unless the temperature be kept at 40° to 50° when β-phenylhydroxylamine is formed; a better yield of the latter (85 to 90 per cent of the theoretical) being obtained by using a cooled solution of the nitrobenzene in ether. Ethyl oxalate thus treated yields ethyl glycollate and alcohol.—*J. pr. Chem.*, II, liv, 18, August, 1896. G. F. B.

9. *The Constants of Nature.* Part V. *A Recalculation of the Atomic Weights.* New edition, revised and enlarged. Smithsonian Miscellaneous Collections. 1075. Washington, 1897.—Prof. Clarke's new and carefully elaborated edition of the re-calculation of the atomic weights, which has recently been issued, will be welcomed by the many chemists who have been benefited by his earlier labors in this line.

10. *Compact apparatus for the study of electric waves.*—Prof. JAGADIS CHUNDER BOSE describes a very compact apparatus for this purpose, which consists in using a spiral steel spring connected with a battery and a galvanometer. The spiral spring serves under different degrees of compression as a *coherer* instead of particles of metals, which have been used by Brady and also by Lodge. The oscillator consists of a central ball of platinum and two small balls one on each side of the central ball. The oscillating sparks occur between the small balls and the central ball. The author has repeated most of the ordinary optical phenomena by means of electric waves.—*Phil. Mag.*, January, 1897. J. T.

11. *A new formula for spectrum waves.*—J. J. BALMERS' empirical formula for calculating the wave length of hydrogen has awakened great interest; for values calculated from his formula agree very closely with the observed values. In this article he reviews the work of Kayser and Runge on formulas for expressing the periodicity of spectrum lines, and also the recent work of Rydberg; and he gives a modified formula. He is convinced that in the spectrum formula originally given the constant n should be extended by a constant fraction. He therefore modifies his formula and writes it

$$\lambda_n = a\,\frac{(n+c)^2}{(n+c)^2-b}$$

in which a has the value of 2300 Ångström units. The paper includes an estimation of the values of c.—*Ann. der Physik und Chemie*, No. 2, 1897, pp. 380–391. J. T.

12. *Discharge rays and the connection between them and the Cathode and Röntgen rays.*—M. WILLIBAD HOFFMANN has studied the luminescence produced in various substances by means of electric discharges of various forms and has traced the phenomena from its beginning in air to its manifestation in rarified media.—*Ann. der Physik und Chemie*, No. 2, 1897, pp. 269–299. J. T.

13. *Large storage battery.*—Professor TROWBRIDGE has had constructed a storage battery of ten thousand cells for the Jefferson Physical laboratory. The details of the battery have been completed with great skill by the mechanician, Mr. G. M. Thompson. The battery gives a voltage of at least twenty thousand, with a current of eight amperes. It is unable to light a Crookes tube. The lowest voltage which will satisfactorily produce the Röntgen rays appears to be one hundred thousand volts. The battery can be employed with great success to charge Leyden jars in parallel and to discharge them in series. A small electric motor is employed to revolve a suitable commutator in order to discharge the Leyden jars rapidly in series. The apparatus is a modification of that first used by Planté. It enables one to study quantitatively the high electromotive force necessary to produce the Röntgen rays. An oscillatory discharge of electricity through a Crookes tube appears to be prejudicial for the development of the X-rays. The best results are obtained without a condenser in series with the Crookes tube. This seems to show that the electrostatic polarization is largely instrumental in the generation of the Röntgen rays. J. T.

14. *Outlines of Electricity and Magnetism;* by CHARLES A. PERKINS. 277 pp. New York, 1896 (Henry Holt & Company).—The author has presented in this little volume the prominent phenomena and principles of electricity and magnetism. Further, he has attempted, and in the main with success, to show how modern theories serve to explain the observed phenomena and to bring out the essential relation between them. Numerous illustrations and analogies are employed and in general in such a way as to materially aid the elementary student to obtain clear ideas of the subjects under discussion.

II. GEOLOGY AND MINERALOGY.

1. *Principal features of the Geology of Southeastern Washington;* by ISRAEL C. RUSSELL. (Abstract furnished by the author.)—The following note gives a brief statement of the results of a six-weeks reconnoissance in the southeastern portion of the State of Washington made for the U. S. Geological Survey.

Practically all of that portion of Washington which lies south of the Big Bend of the Columbia is occupied by a succession of basaltic lava flows. This is a portion of a vast lava-covered region embracing northern California, central and eastern Oregon, central and southeastern Washington and southern Idaho. The great fissure eruptions which supplied the Columbia lava, as the basalt is termed, occurred in the Miocene.

The Columbia lava in Washington to the west of the Columbia and south of the Big Bend, as ascertained during a previous reconnoissance, is broken by extensive faults and the blocks thus formed variously tilted. In the region here treated, however, the basalt is horizontal over extensive areas, and deeply dissected by Snake river and its tributaries.

Many lava sheets, one resting on another, were seen. Between some of the flows there are widely extended sheets of lacustral clays, sand, gravel, volcanic dust and lapilli. In some instances leaves and the silicified stumps and trunks of trees occur in these layers.

The Columbia lava flowed about the bases of the mountains of eastern Washington and the adjacent portion of Idaho, in a series of inundations which covered the low country to the south. The level basaltic plateau meets the mountains of metamorphic rock in much the same manner that the sea joins a rugged and deeply indented coast. The lava entered the valleys and gave them level floors of basalt; the deeply sculptured ridges between the valleys were transformed into capes and headlands; outstanding mountain peaks became islands in the sea of molten rock.

After the last of the lava sheets was spread out, the rivers flowing from the mountains began the excavation of channels across the basaltic plateau and have deeply dissected it. The most important of these channels is the one cut by Snake river. From the mouth of Snake river to Lewiston, the stream is in a comparatively narrow steep-sided canyon about 2000 feet deep. Where Snake river forms the boundary between Washington and Idaho, its gorge is about 4000 feet deep and 15 miles broad. Within this vast gorge there are many lateral ridges, and a great variety of topographic forms due to erosion. This portion of Snake river canyon compares favorably with even the most magnificent parts of the Grand Canyon of the Colorado, except that it lacks the gorgeous coloring to which so much of the charm of its southern rival is due.

The thickness of horizontally-bedded basalt exposed in the walls of Snake river canyon and in the adjacent Blue mountains, is in the neighborhood of 5000 feet, but the maximum thickness is not revealed. In the walls of the canyon at three localities the summits of steep, angular mountain ranges are exposed; one of these buried peaks rises about 2500 feet above the river and is covered by fully 1500 feet of horizontally-bedded basalt.

The sheets of clay, sand and gravel interleaved with the basalt, especially near its junction with the bordering mountains, furnish conditions favorable for obtaining artesian water. A number of flowing wells derive their water supply from this source.

The Blue mountains, at least at their northern extremity, consist of a broad, low, flat-topped dome of basalt which has been deeply dissected by consequent streams. The layers of basalt in the uplifted region are still horizontal except about its borders, where gentle outward dips occur.

The surface of the basaltic plateau is covered with residual soil, which has an average depth of 60 to 80 feet over thousands of square miles. The soil is exceedingly fine, dark brown or black in color and of wonderful fertility. This is the soil of the celebrated wheat lands. The sub-soil is fine, light yellowish in color, without stratification, and in many localities traversed by minute, irregular, but in general vertical tubes. In many ways this subsoil resembles loess. Its origin from the disintegration and decay of the underlying basalt is clearly manifest.

Topographically the lava-covered region presents great diversity. In the Blue mountains there is an intricate series of sharp-crested ridges separated by a labyrinth of canyons, having in general a depth of about 3000 feet. Between the Blue mountains and Snake river on the north there are broad remnants of the nearly level plateau separated by narrow steep-sided canyons, in general 2000 feet deep. North of Snake river there is a vast area without deep canyons, but diversified by short hills, from 50 to 80 feet high, none of which, however, rise above a certain general level. Along the eastern portion of this hilly plateau or rolling prairie, as it was before cultivation began, there are a few prominent island-like buttes of quartzite, which rise through the basalt.

Among the details noted in the Columbia lava are certain horizontal joints which cut the vertical columns of basalt and in some cases may be traced for several miles. The large vertical columns of lava when weathered, occasionally show that they are composed of small horizontal columns or prisms, which radiate from a confusedly jointed, central core. The joints which bound the large vertical columns furnished the cooling surfaces for the rocks they enclose. The bases or ends of the radiating columns are frequently revealed on the surfaces of the slightly weathered vertical columns by a net-work of lines resembling shrinkage cracks.

A report on the observations outlined above will be published by the U. S. Geological Survey.

2. *Geologic Atlas of the United States Yellowstone National Park, Folio, No. 30, U. S. Geol. Surv., 1896.*—It seems safe to say that probably no other one of the atlas sheets issued by the Geological Survey will command more attention than this. The National Park has become so widely known and its marvels are so directly conducive to geological inquiry, that anything of a nature to be useful to the general public as well as to scientific men will certainly be appropriated with eagerness, and soon put to practical use.

The present atlas contains a topographic map of the park on the scale of 1:125,000, i. e. two miles to an inch, in four sheets. The triangulation and topography of these maps is by J. H. Renshawe, H. S. Chase, F. Tweedy, W. H. Leffingwell, and S. A. Aplin, Jr.

The geological maps are also four in number, corresponding to the topographic maps above. The geology is by Arnold Hague, J. P. Iddings and W. H. Weed, the former being in charge of

the work. Five pages of text written by Mr. Hague accompany the maps, giving a clear and admirable résumé of the geological history of the Park; there is an additional page by Mr. Iddings on the igneous rocks which play so important a role in the geology of the district. There are also three pages devoted to the reproduction of photographs of a striking character illustrating different objects of geological interest.

The economic maps of the general atlas sheets are of course wanting. The work is a superb example of the engraver's and printer's art.

Now that this interesting work has been issued, the advent of the special report on the geology of the district will be eagerly looked for and we trust that it may not be long delayed.

L. V. P.

3. *Report of the Director of the United States Geological Survey for the year 1895–96 ;* by CHARLES D. WALCOTT, Director. (Extract from 17th Ann. Rept. U. S. G. S., Part I), pp. 1–200. 1896.—In addition to the usual report of the detailed work of the Survey the director calls attention to the law passed by Congress, June 11, 1896, providing for the monumenting of the topographic surveys. The provision is embodied in the following clause in the sundry civil appropriation act of above date:

"*Provided*, That hereafter in such surveys west of the ninety-fifth meridian elevations above a base level located in each area under survey shall be determined and marked on the ground by iron or stone posts or permanent bench marks, at least two such posts or bench marks to be established in each township or equivalent area, except in the forest-clad and mountain areas, where at least one shall be established, and these shall be placed, whenever practicable, near the township corners of the public-land surveys ; and in the areas east of the ninety-fifth meridian at least one such post or bench mark shall be similarly established in each area equivalent to the area of a township of the public-land surveys."

This provision, passed at the instigation of the Director, will greatly increase the value of the geologic survey work, both to geologists and to inhabitants of the territory surveyed.

The geologic work was carried on by twenty-eight field parties, the paleontologic work by six field parties. In the division of hydrography, field operations, under the general charge of Fred. H. Newell, were carried on in various regions of the United States, classified as humid, sub-humid and arid. A large list of rivers were systematically measured, classified under sixteen great river basins. The topographic branch of the survey during the year was reorganized, the classification into four sections being retained in charge of the same chiefs as heretofore, but the director assumed the immediate charge of the whole. There were forty topographic parties working in twenty-five different states and territories connected with this important branch of the survey, and 48,066 square miles were surveyed during the year.

In the editorial division 12,875 manuscript pages and 4627

printed pages were edited, and twelve geologic folios were published.

The library of the survey, which is becoming remarkably complete, has reached the total number, of books, pamphlets and maps, of 127,285. The appropriation for the fiscal year 1895–96 was $521,890. H. S. W.

4. *Geology of the Castle Mountain Mining district, Montana;* by W. H. WEED and L. V. PIRSSON. Bull. No. 139, U. S. G. S., pp. 1–164, pl. i–xvii, figs. 1–11, 1896.—This memoir is a general description of the geological features mapped on the Little Belt Mountains sheet, based upon field work done by the authors during the years 1892 and 1893, containing detailed account of the sections of the Algonkian, Cambrian, Carboniferous, Cretaceous and Miocene beds with reference to Silurian, Devonian and Juratrias outcrops, together with lists of fossils when obtained. The igneous rocks are described with fuller details, both petrographic and chemical, and chapter ix is devoted to study of the glacial phenomena of the region. Chapters x and xi give a summary of the economic and mineral products of the region. H. S. W.

5. *The Eocene deposits of the Middle Atlantic Slope in Delaware, Maryland, and Virginia;* by W. B. CLARK. Bull. No. 141, U. S. Geol. Surv., pp. 1–167, pl. i–xl, 1896.—In this Bulletin is brought together a thorough account of the Eocene deposits of this region and their faunas based upon original investigations. Many new species are given, which with the known species are fully illustrated. The conclusions reached are given in a paper in this Journal.* An excellent brief synopsis of the criteria employed in the correlation of sedimentary rocks is given on pages 47 to 58. H. S. W.

6. *Catalogue des Bibliographies Géologiques rédigé avec le concours des membres de la Commission bibliographique du Congrès par* EMM. DE MARGERIE. Congrès Géologique International 5me Session, Washington, 1891, 6me Session Zürich, 1894, 733 pp., Paris, 1896 (Gauthier Villars et Fils).—This exhaustive bibliography of bibliographies of geological works, containing 3918 entries, is the first published result of the international committee on geological bibliography organized at the Washington meeting of the *Congrès géologique international* in 1891.

The commission was entrusted with the threefold task of 1st, preparing a list of existing bibliographies of geology, whether separate works, lists in connection with special treatises or reports, or private lists or card catalogues, so far as known, in all countries and languages; 2d, provoking societies and geological surveys, operating in countries in which such lists have not been prepared, to prepare detailed catalogues of the works relating to the geology of their respective territories; and 3d, preparing for the periodic (annual if practicable) publication of the current bibliography, to be published immediately after the close of the period covered. The first of these tasks is accomplished in the present

* This Journal, IV, vol. i, pp. 365–374.

work; and all working geologists owe a deep debt of gratitude to the committee and, particularly, to the secretary, M. de Margerie, for the admirable results of their labors.

The arrangement and classification of the material is such as to make the work most useful. The plan of the work is as follows: The first classification of the matter is into a general and a regional part. The first part contains A. Histories and Bibliographies of general geology, B. Periodic bibliographies, C. Personal bibliographies, D. Bibliographies by subjects, E. Geographic geology in general. The second part, regional, contains separate lists for each separate European state (or group of states in a few cases), and each important country or group of countries outside Europe. Under each of these regional groups, the lists are classified under the following heads: 1, generalities, 2, catalogues of publications of official geological surveys, 3, general tables of the contents (periodic) of society and academy publications, 4, periodic bibliographies, 5, catalogues of booksellers, 6, personal bibliographies, 7, bibliographies arranged by subjects, 8, regional and local bibliographies.

Full titles are given throughout the work, and, in a large number of entries, brief notes indicate the special field covered by the volume or reference cited. The particular pages in which the bibliographic matter is found is also indicated in detail, a feature which will be appreciated by the busy student.

The committee is composed of fourteen members, each a prominent, active geologist of the country he represents, thus ensuring thorough and accurate work. We congratulate the indefatigable secretary, M. de Margerie, upon the completion of this work, which will be appreciated most highly by those who know something of the great labor involved in preparing it.* H. S. W.

7. *The Yellow Limestone of Jamaica;* by R. T. Hill (from a letter to Prof. A. Agassiz, dated Kingston, Feb. 2d).—My enforced stay at Kingston has resulted in the discovery that nearly all the so-called "Yellow Limestone" formations of Sawkins are *Cretaceous.* I have collected fossils in them at many localities; including Rudistes from the very top series at Catadupa and in the province of Clarendon.

8. *Handbuch der Mineralogie* von Dr. C. Hintze. Neunte bis zwölfte Lieferung. Leipzig, 1897 (Veit & Co.)—Mineralogists in all lands will congratulate Dr. Hintze, and themselves as well, on the completion of volume ii of his monumental work on Mineralogy—the most exhaustive treatise ever attempted. The parts now issued embrace pages 1281 to 1842 and include, besides some other species, the feldspars, scapolites, and zeolites. A considerable time has elapsed since the appearance of the preceding eighth part, but workers in mineralogy will be reconciled for this in receiving at once the four parts here alluded to; moreover, they will now look forward with confidence to the completion of the whole work. The thoroughness and accuracy, which characterize Dr. Hintze's labors as an author, are too well known to need to be enlarged upon.

* We are informed that copies of this work may be obtained for $5, from Mr. G. K. Gilbert, U. S. Geol. Survey, Washington; the Compte Rendu of the Washington Congress will be sent to purchasers by Mr. S. F. Emmons.

III. Miscellaneous Scientific Intelligence.

1. *Annals of the Astronomical Observatory of Harvard College.*—Part 4 of volume xxx and Part 5, vol. xl, recently received, contains the results of observations made at the Blue Hill Meteorological Observatory, Mass. The former volume is devoted to a paper by H. Helm Clayton on the discussion of cloud observations. It opens with an historical sketch of cloud nomenclature, which is followed by a statement of the new system founded upon the international nomenclature. The relations of clouds to rain-fall, cyclones, movements of the wind, and many other points, are discussed in detail, with other related subjects. The memoir is accompanied by seventeen plates, showing particularly the relation of the cloudiness in general, and the different forms of clouds, to the movements of cyclones and anti-cyclones.

Circular, No. 15, by E. C. Pickering, discusses the remarkable results obtained in photographing the stars by the Bruce photographic telescope and the subject is illustrated by some beautiful plates. Circular, No. 16, gives measurements of the spectrum of ζ Pupis.

2. *Smithsonian Physical Tables;* prepared by Thomas Gray. pp. xxxiv and 304. Washington, 1896. (Smithsonian Miscellaneous Collections, 1038.)—This volume forms the third part of the new series of Smithsonian tables planned by the Secretary, Prof. S. P. Langley. The first volume, which was issued in 1883 (see this Journal, xlvi, 160), comprised the meteorological tables; the second, issued in 1894 (xlix, 327), included the geographical tables, and was prepared by Prof. R. S. Woodward. This third part includes the physical tables and has been prepared by Prof. Thomas Gray, of Terre Haute, Indiana. The introduction is given up to units of measurement and conversion formulæ, and then follow 315 tables relating to all the different departments of physics, but so varied in character that it is impossible to mention them individually. The value of so large and so carefully compiled a series of tables of physical constants is obvious and need not to be insisted upon.

3. *North Carolina and its Resources.* Issued by the State Board of Agriculture. 413 pp. with a map and numerous illustrations. Raleigh, 1896.—This handsome volume discusses the resources of North Carolina in all their varied aspects, economic and scientific. It thus contains much matter both of local and general interest. A large number of excellent plates show features of the scenery, agricultural industries, public buildings, etc., and add much to the attractive character of the volume.

4. *The National Museum.*—By the action of the Board of Regents of the Smithsonian Institution at its last annual meeting, Chas. D. Walcott, Director of the U. S. Geological Survey, was appointed Acting Assistant Secretary, with the understanding that his duties would be exclusively confined to the charge of the Museum, and that the appointment be considered as temporary until a permanent successor to the late G. Brown Goode shall be appointed.